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Office of Naval Research Asian Office
NAVSO P-3580 Vol 17, No. 1 January–March 1992

AD-A248 713

SCIENTIFIC INFORMATION BULLETIN

DISTRIBUTION STATEMENT A
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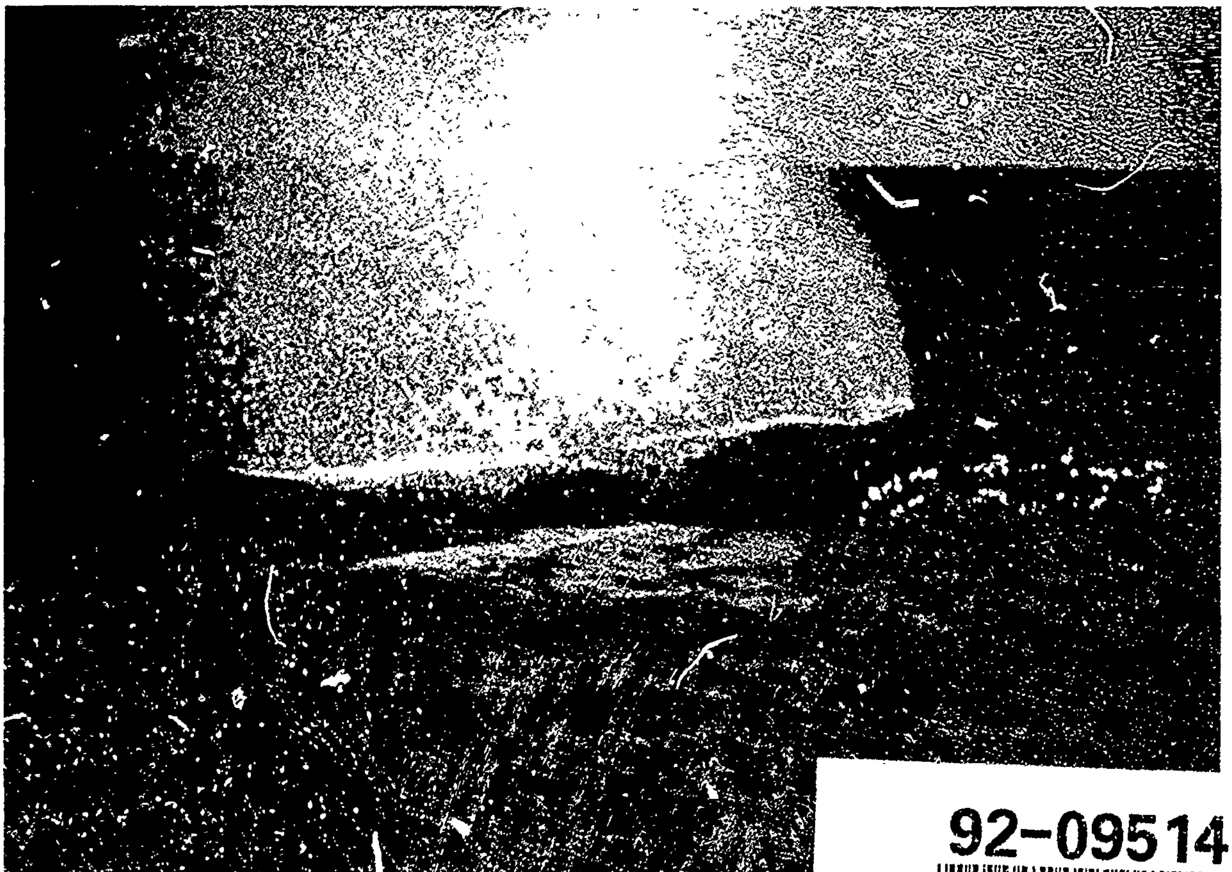

92-09514

92 4 13 085

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE Jan-Mar 1992

3. REPORT TYPE AND DATES COVERED

4. TITLE AND SUBTITLE

ONRASIA SCIENTIFIC INFORMATION BULLETIN

5. FUNDING NUMBERS

6. AUTHOR(S)

Sachio Yamamoto, Director; Sandy Kawano, Editor

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Office of Naval Research Asian Office
Unit 45002
APO AP 96337-0007

8. PERFORMING ORGANIZATION REPORT NUMBER

ONRASIA Vol 17, No. 1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

ISSN: 0271-7077

12a. DISTRIBUTION/AVAILABILITY STATEMENT

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONRASIA, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest. This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large. It is available free of charge to approved members of the DOD scientific community. Send written request describing DOD affiliation to: Director, Office of Naval Research, Asian Office, Unit 45002, APO AP 96337-0007.

14. SUBJECT TERMS

Computer security	Case-based reasoning	Software
Parallel processing	Numerical algorithms	Supercomputers
Fuzzy systems	Computer reliability	Computer vision

15. NUMBER OF PAGES 140

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18

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Availability Codes
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Materials Science

Ocean Science

Cover: The humpback whale. One of the first priorities for the South Pacific Environmental Program's (SPREP) proposed Marine Mammal Action Plan is to access humpback whale breeding populations in the region. Historically, the SPREP region contained many breeding sites for both the northern and southern hemisphere stocks. Contemporary breeding sites are poorly understood. Research programs would include surveys to identify the sites and the use of natural markings for individual identification. Photo courtesy of Gregory Stone (see his article on SPREP on page 137).

SIBRIEFs

Scientific Information Briefs

SUPERCOMPUTING BENCHMARK PROPOSAL

Recently, four Japanese scientists, Wong Weng Fai [wong@rkna50.riken.go.jp], Eiichi Goto, Yoshio Oyanagi [oyanagi@is.s.u-tokyo.ac.jp], and Nobuaki Yoshida [nyoshida@rkna50.riken.go.jp], have proposed two sets of benchmark problems for supercomputers. Goto was the director of the University of Tokyo Computer Center until he retired in March 1991. He is now at Kanagawa University. Oyanagi is a central researcher in the QCDPAX parallel processing project at Tsukuba University, although he is now at the University of Tokyo.

Their proposal allows for maximum freedom for programmers within the constraints of the given problem to select the language, programming style, algorithm, and optimization necessary to get best performance for solving the given problem on a given machine. Performance is measured in terms of number of outputs per unit time or time taken to produce a specified unit of output.

Six basic problems are

- Random number generation
- Elementary function generation
- Fast Fourier transform
- Dense matrix computation
- Rule-specified sparse matrix computation
- List-vector-specified sparse matrix computation

They believe that these represent a significant cross section of fundamental scientific computations and that by allowing programmers to exercise total freedom in coding the programs to solve these, the resulting benchmark figures will better reflect the underlying architecture of the given machine.

In addition, they propose three additional problems

- Modular dip
- Memory hierarchy
- Burst mode

that are meant to highlight subtle hardware characteristics not exposed by the basic problem set.

The motivation for these proposed benchmarks is to reflect fundamental and frequently used capabilities of supercomputers; to reflect chaining of arithmetic logical units, which is a key feature of today's supercomputers; and to reflect the memory addressing capabilities of these machines.

Benchmarking is an important subject both in the United States and European Community. Major projects are in progress at Los Alamos, the National Aeronautics and Space Administration, Illinois, and many other places. This summer there was a very small workshop on benchmarking between the United States (six persons) and Japan (four persons) on Kauai, Hawaii. Oyanagi told me that he felt the underlying trend was that the U.S. participants were more interested in benchmarking applications, while Japanese (including Oyanagi) stressed the importance of architecture. He felt that one reason might be that the U.S. participants were mostly related to big supercomputer centers and had different responsibilities than the Japanese.

There are two upcoming supercomputing meetings, one in Fukuoka, Japan, from 7-9 November 1991 and another in Albuquerque, NM, from 18-22 November 1991. I think it would be valuable to have discussions on this proposal during these meetings. I also hope that some of the summer workshop participants will provide a summary. Oyanagi is hoping to participate in a panel discussion at the Fukuoka meeting and may present a paper as well, but he will not be in Albuquerque.--*David K. Kahaner, ONRASIA*

* * * * *

APPLIED MATHEMATICS WORKSHOP

The primary goal of the workshop, which was held from 11-12 August 1991 at Tokushima University, was to facilitate the exchange of ideas on recent developments in applied mathematics by bringing together active researchers from universities and industrial laboratories. In Japan, interaction between these two societies has been rather limited. One of the principal organizers, Prof. Kametaka of Tokushima University, expressed hope that opportunities for meeting, establishing friendships, and promoting understanding between different communities would increase, through small, informal workshops as this one at Tokushima.

The workshop consisted of 14 50-minute talks on ordinary and partial differential equations (ODEs and PDEs), numerical simulation, and

modelling. The presentations ranged from very mathematically abstract material to practical problem solving through numerical simulations. Computationally oriented talks were given on the first day and more theoretical discussions on the second. Approximately 50 scientists attended.

The three talks given by Japanese industrial researchers were on control theory and fuzzy logic (Fuji Electric), scientific visualization systems (IBM Tokyo Research Laboratory), and gas-solid flow simulation of discharge of powder coal from a bin (Kobe Steel).

The first talk consisted of some basics of control theory and feedback systems and mathematical modelling of systems and processes. Unfortunately, time limitations only allowed the speaker to mention fuzzy logic during the last few minutes, and specific applications of the theory to systems at Fuji Electric were not presented. During the question-and-answer session the speaker did, however, touch upon the difficulties of constructing more intelligent camera systems.

The second talk began with an overview of graphics tools developed at IBM. The capabilities of the tools were illustrated through specific examples, i.e., visualization of air and dust flow pattern simulation inside cleanrooms and memory disks, three-dimensional translucent imaging of brain tumors, and modelling and rendering of varieties of textures. The overview concluded with a 3-minute video of Edo Castle that was presented at SIGGRAPH. The remainder of the talk consisted of a short presentation on the speaker's work on inverse Sturm-Liouville problems and an image compression/decompression system being developed using wavelet theory.

The presentation on gas-solid flow simulation opened with an introduction to the flow equations. Numerical calculations of specific examples were discussed in great detail, and a formal write-up of the speaker's work was distributed. Requests for copies should be addressed to H. Nakanishi and S. Toyoshima at the Mechanical Research Laboratory of Kobe Steel, Kobe, Japan.

Following a Japanese tradition or initiation rite, three students (Kimura of Kyoto RIMS, Sasamoto of Chiba University, and Saw Win Maung of Chiba University) presented their recent findings in numerical analysis. Saw Win Maung is one of a growing number of foreign students studying in Japanese universities. His presentation was, quite impressively, given in Japanese.

The remainder of the talks were from young academicians who often attend the Mathematical Society of Japan and Kyoto RIMS meetings. Their work is already widely known in the general mathematical community.

Proceedings from the workshop will be compiled by Prof. Kametaka of Tokushima University and should be available by mid-October 1991. Inquiries should be addressed to

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--*Mei Kobayashi, IBM Japan*

* * * * *

JAPANESE NATIONAL AEROSPACE LABORATORY'S (NAL) COMPUTING DIRECTIONS

A major application of supercomputing is to the design of airplanes and related vehicles. In fact, the goal of aircraft designers is to be able to simulate with fine spatial resolution the air flow over a complete plane. Simulations can be done now, but computer time and memory limit the practical resolution that can be achieved. This is a worldwide research activity. Theoretical and algorithmic developments have been significant since the 1930s, earlier for some situations.

A very excellent statement of at least one Japanese scientist's opinion of this field was recently given by Prof. Kunio Kuwahara in an interview with Jaap Hollenberg in *Supercomputer*, July 1991 (ISSN 0168-7875): "We need more power and less modeling." Kuwahara runs the Institute for Space and Astronomical Sciences (ISAS) in Tokyo. His view is a very conservative one:

> I am only a computer user not a computer architect. I am only interested in solving partial differential equations. ... We just solve the Navier-Stokes equation, that is all; very easy. ... I do not like to model. I like a direct approach to that phenomenon [turbulence], and take a very fine grid, then it is not difficult anymore, the difficulty is only the computer power.

When asked about special-purpose computers, Kuwahara remarked that these "will always become obsolete very soon, because you cannot change it. My vector machines are rather flexible."

Recently, a colleague mentioned to me that at the Ninth Plane Computational Aerodynamics Symposium, 12-14 June 1991, held at the Japanese National Aerospace Laboratory, another view was presented in a paper titled "Specifications for a Parallel Computer for CFD," by

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I was told that Dr. Miyoshi's paper proposed a system of more than 100 processors, connected via a full cross-bar network (so that each processor can communicate quickly with any other), allowing 400-MB/s communication between each pair, with a total communication capacity of 80 GB/s. Each processor should be faster than a Fujitsu VP-400. This would be a distributed machine, with each processor having 256 MB mail memory, 128-KB vector registers, and 64-KB cache. I was also told that Fujitsu's researchers gave a few research talks about such a system and suggested that it might be able to be built within 3 years. The symposium was held in Japanese and a Proceedings has not yet been published.

I went to NAL to visit Dr. Miyoshi to hear more of the details. Miyoshi speaks very little English and asked that I bring a translator so that there would be no misunderstandings. He was quite concerned about recent U.S./Japan frictions in the area of supercomputing. I was accompanied by Mr. Frank Nagashima from my office. With Miyoshi was Dr. Toshiyuki Iwamiya, senior researcher in Miyoshi's Computational Sciences Division. Iwamiya can also be reached by E-mail at [iwamiya@aerospace-lab.go.jp].

Miyoshi told us about the history of computing at NAL, which is built around Fujitsu equipment. NAL has been using Fujitsu hardware since the late 1970s. (See a brief description of NAL below.) He explained that his paper (which is not yet available) was simply a statement of some of his ideas and does not represent any concrete plan. He commented that about 2 years ago NAL approached a number of computer vendors, including Cray Japan, IBM Japan, Unisys, NEC, Fujitsu, and other Japanese companies, for assistance in developing, at least at the specification level, a machine that would be appropriate for numerical wind tunnel simulation. He explained that at the time the first three declined to participate, although the others have had some collaborations and a manuscript summarizing their findings might be available in May 1992. Presumably their research is continuing--as we were leaving, we met Dr. Tadashi Watanabe, NEC's Assistant General Manager for EDP Product Planning, and a key figure in the development of the SX-3.

Miyoshi explained that a system similar to the one I mentioned above might be possible with BiCMOS, as 1,000 pin-outs may be realizable, but that problems with energy consumption and maintenance were uppermost in his mind. Miyoshi, as the director of a computing facility that must serve a large number of scientists, seemed more interested in capabilities for the many than for the few. However, in summary, Dr. Miyoshi wanted to emphasize that the parallel machine I asked him about was simply a proposal, not a plan.

NAL is roughly similar in mission to the National Aeronautics and Space Administration in the United States, but much smaller. Founded in 1955, its current mission is to establish the necessary technologies for future development of aircraft in Japan and to perform research in those areas necessary for future Japanese space development. NAL is operated as one of the bodies under the Science and Technology Agency. NAL's main headquarters are in Chofu, about 30 minutes outside Tokyo. There is also a smaller research center in Kakuda, near Sendai. NAL's budget has been about $70M for a number of years; staffing has been slowly decreasing from nearly 500 in the late 1960s to 439 in 1991. Miyoshi's Computational Sciences Division performs research in nonlinear phenomena, numerical simulation, artificial intelligence, and image understanding.--*David K. Kahaner, ONRASIA*

* * * * *

WAVELETS SEMINARS IN TOKYO

Five seminars on wavelets and their applications were sponsored by SIAM Japan on 14 November 1991. Although most of the talks did not contain any new research announcements, two of the presentations are worth mentioning.

Hideki Kawahara, from the NTT Basic Research Laboratories, discussed techniques for illustrating sound using graphics. He covered everything from standard black-and-white, two-dimensional (2D) graphs to three-dimensional (3D) color surfaces of wavelets. Kawahara commented that he does not use the sophisticated 3D rendering techniques used at IBM Research. He proceeded to explain the biological aspects of voice generation and reception. In summary, Kawahara presented physiological evidence on how wavelets are better suited for acoustical signal processing than currently employed techniques. Sound decomposition using wavelets was described, and both female and male voices were used in a demonstration that showed how the amount of information needed to convey human speech could be significantly reduced but not detected by the human ear if wavelets are used rather than conventional techniques.

Researchers interested in this area might contact Kawahara at NTT. He is conducting interesting and original work on sound processing with emphasis on voice (probably for phone transmission since he's from NTT).

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Prof. Yamada, from the Department of Civil Engineering, Kyoto University, discussed singularity analysis and

detection. The example used was the standard 1/3, 1/3, 1/3 Cantor set from undergraduate mathematics. The talk was based on research work by Vergassola using the Mexican Hat and French Hat wavelets. For singularities of a known order, wavelets can be used to verify the order. The remainder of the talk focused on the open question of whether wavelets can be used to determine the order of a singularity. Vergassola's work shows how to "clean" data to estimate the order but could not concretely answer the question.-- *Mei Kobayashi, IBM Japan*

* * * * *

RESEARCH INSTITUTE OF MATHEMATICAL SCIENCES (RIMS) WORKSHOP ON NUMERICAL ALGORITHMS

This workshop is one of a series of six sponsored annually by the Research Institute of Mathematical Sciences (RIMS) of Kyoto University during the fall-winter period. The organizer of the workshop was

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The talks on the first afternoon were rather unusual in that they emphasized computations and visualization of the results. Three color videos (by S.-R. Zhan, M. Mori, and the author) showed how new technologies could be used to enhance understanding of mathematical and numerical work. Zhan [Institute for Computational Fluid Dynamics (iCFD)], a recent graduate of Tsukuba University and a former student of Mori, began the session with results from a study comparing Bi-CG, CGS, and Bi-CGSTAB methods for solving the two-dimensional Laplacian with an inhomogeneous sinusoidal term on the unit square with general boundary conditions.

The second speaker, S. Fujino, also from iCFD, summarized both his and Zhan's talks in commenting that Bi-CGSTAB is superior in that it does not oscillate widely as it converges towards the desired solution, whereas the other two methods do and may mislead a naive scientist. During the question-and-answer (Q&A) session he commented that Van der Vorst announced an improved version, Bi-CGSTAB II, 2 weeks ago in Zurich; however, implementation of this upgraded version has not yet begun at the Institute for Computational Fluid Dynamics (iCFD).

Mori's (University of Tokyo) talk was on a three-dimensional (3D) extension of a two-dimensional (2D) approximation of a blast furnace problem [2D reference: M. Mori, M. Natori, and Zhang Guo-Feng, *Intl. J. Num. Meth. Fluids*, 569-82 (1989)].

The author's talk began with illustrations of simulations using the latest IBM graphics technologies. Modelling and rendering techniques were also illustrated through an award-winning video, "Edo," by Miyata, also of IBM. The latter half of the talk was on the topic of processing of the graphics and image data using the Haar wavelet basis. Although only two-dimensional results were shown, the author explained that level sets of 10 2D layers have been generated and will be released when 32 or more 2D layers are used.

Two talks on TeX and LaTeX stirred up heated discussion (an unusual event for a Japanese mathematical meeting). The first TeX talk by T. Nodera (Keio University) began with the birth of TeX as a word processor for "A Christmas Carol" in 1978. The history of TeX was outlined from version 0.5 to 0.99 until the release of TeX 1.0 in July of 1982 at a Stanford University conference. (The release date was purposely designed to coincide with the first distribution day of Knuth's classic, *TeX Book.*) Enhancement continued from versions 1.0, 1.1, 1.2, 2.0, 2.99, to 3.0 in 1990, then 3.14 and upwards. (TeX is expected to converge to pi upon Knuth's death according to his will.) Note: the casual user will not be able to distinguish the difference in versions 3.0 and above. In the same vein, Meta Font is being upgraded from 2.0 to 2.7 and upwards and is expected to converge to e upon Knuth's death. Nodera spent the latter half discussing how the multi- and two-column styles differ and how to play tricks to format a paper with an abstract to conform to the Information Processing Society of Japan (IPSJ) document style. "Why not simply cut and paste?" asked an irritated listener. This was the beginning of a discussion on the quotation of the day, "We are in the business of doing mathematics, not publishing."

The next talk on Springer-Verlag's TeX Macropackage was equally, if not more, controversial. The speaker noted the trend towards electronic submissions to prestigious journals and book publishers. Details on accessing and using Springer's new package were outlined. The Q&A session became heated once again. To summarize, a significant portion of the audience seemed concerned about whether the use of certain formatting styles and electronic submissions to journals would become mandatory. The announcement that Springer asks for DVI rather than the original TeX file brought forth very strong negative reactions from the audience. Concerns were also voiced regarding trouble by some Japanese universities in recruiting young researchers because of comparatively poor E-mail or networking services.-- *Mei Kobayashi, IBM Japan*

* * * * *

TRONSHOW '91

Introduction

K. Sakamura (University of Tokyo), the originator of the TRON concept, again had an impressive list of supporting and sponsoring organizations for this second show: the Ministry of International Trade and Industry (MITI), the Ministry of Posts (MOP), and the Science and Technology Agency (STA); computer manufacturers; and construction companies. [See also the report by D.K. Kahaner, "TRON (The Real Time Operating System Nucleus," *Scientific Information Bulletin* 16(3), 11-19 (1991).] The newly formed TRON Multimedia Broadcasting Company (TMBC) was taking on-the-spot shots to include them in its multimedia show. All together about 20 companies displayed products and applications in booths In addition, a central theater was used to explain ideas and products through video demonstrations.

Among the exhibitors, all Japanese computer manufacturers were present with the notable exception of NEC. NEC has been reluctant to join the TRON project because it is successfully marketing MS-DOS/Windows/Unix machines and because it has developed its own series of Intel-compatible microprocessors, the V-series. The multiprocessing units (MPUs) at the lower end are already replacing the Intel processors due to their superior performance. On the software side, NEC is, however, using ITRON specifications as real-time kernel in its real-time Unix operating system (OS), called RX-UX832.

The activities of TRON comprise two lines:

(1) Development and implementation of multitask, real-time OSs (CTRON, ITRON + subset myITRON, BTRON).

(2) Development of microprocessors for TRON OS (not compatible with Intel or Motorola processors).

This is not an exclusive relationship: TRON MPUs are also used for Unix implementations and TRON OSs are successfully implemented on, e.g., Intel MPUs.

Software

Fujitsu is marketing a real-time OS, based on ITRON specifications, called REALOS/Gmicro. Oki introduced its real-time OS RG68KS, based on CTRON specifications. BTRON with its object-oriented features and its graphical user interface (GUI) is making some progress in the direction as OS for multimedia. The Multimedia Working Group has proposed an experimental system, connecting BTRON workstations via ISDN to form a conference system. On the other hand, Wind River Systems (U.S.) brought their real-time OS VxWORKS on the Gmicro processors.

Microprocessors

There were no new developments except customizable versions of 32-bit processors and downscaling to 16-bit processors. Within the "Gmicro" microprocessor line (Fujitsu and Hitachi, Oki), Fujitsu presented the Gmicro G32 series, 32-bit MPUs with the /300-version at the upper end, achieving 24 MIPS at 33 MHz. There have been plans for high performance MPUs /400 and /500 for some time. A broad range of peripheral chips by Fujitsu is available. In addition, a multimedia board using a F32/300 (32 MIPS) processor developed by Genesys, using the TRON application databus (TAD), is able to handle all kinds of media. Hitachi presented the H32-series with a program similar to that of Fujitsu. A separate line is under development by Toshiba with a 32-bit TX1 processor available and a TX2 and TX1ASSP announced. In addition, there is a 16-bit control processor TLCS900 with a real-time OS based on myITRON, called TR900. Matsushita showed its MN10400 (32-bit) MPU with 20 MIPS (maximum) for fast execution of TRON commands. An OS ITRON is available. Also, a 16-bit MPU MN10300 using myITRON was developed.

Some Systems

The electric machinery maker Meiden presented a workstation for factory automation. The machine is based on NEC's 32-bit MPU V80, which runs NEC's RX-UX832 real-time Unix, which is composed of Unix V and ITRON as real-time kernel. It provides peripheral boards for multichannel communication and Meiden real-time Basic (MRTB) for parallel execution. A simpler system for factory automation (FA), called TB-100, is produced by Nihon Minicomputer Systems. It uses the Gmicro/100 processor and ITRON as OS. As an embedded system, Mitsubishi Electric showed a test version of a fax machine using myITRON to handle all functions of the machine and a color copier with an outline font driver using Gmicro processors. Another application was a controller for a small robot. Originally a publishing house, Personal Media Co. presented a notebook computer [hardware (Intel 386) by Matsushita] with BTRON as OS with a Windows-like user interface. As applications a simple wordprocessor, graphic editor, etc. are available. In addition, the company has developed a workstation using TRON microprocessors and an OS "B2" based on BTRON specifications. Japan Airlines is using terminals with BTRON OS to access its passenger reservation system AXESS, and Matsushita introduced its educational computer based on BTRON1 specification, called PanaCAL ET.

Summary

There is a full line of 32-bit microprocessors available that are free of foreign property rights, and in the next stage 64-bit processors are to be expected. On the other side, 16-bit processors have been introduced for cost efficient process control. There seems to be a rising interest in using ITRON and myITRON in multifunctional fax, video recorders, video cameras, printers, etc., using both MPUs with TRON specifications and non-TRON processors. Business applications, where BTRON is competing with existing Unix software, are still in an experimental stage. Multimedia applications, however, should help to promote BTRON with its real-time processing potential. In addition, Sakamura's ideas concerning TRON houses, TRON buildings, and the TRON Computer City in Chiba Prefecture will further promote the TRON standards with their coherent design for all kinds of applications ranging from embedded microcomputers to large-scale distributed computer systems.--*Ulrich Wattenberg, GMD*

* * * * *

FRIEND21

The 1991 International Symposium on Next Generation Human Interface was held from 25-27 November 1991 at Keidanren Kaikan, Tokyo. FRIEND21 is a Ministry of International Trade and Industry (MITI) project related to human-computer interface technology that started in 1988. After the domestic symposium in June, this meeting was turned international by the invited speakers [See also the report by D.K. Kahaner, "Virtual Reality," *Scientific Information Bulletin* 16(4), 43-45 (1991).] The audience of 600 was Japanese with a very few non-Japanese participants. From abroad the presenters were: William Buxton (University of Toronto, Canada); Philip Cohen (SRI, U.S.); Gloranna Davenport (Massachusetts Institute of Technology, U.S.); Jonathan Grudin (University of California at Irvine, U.S.); D. Austin Henderson (Xerox, U.S.); Marilyn Mantei (University of Toronto, Canada); Gary Olson (University of Michigan, U.S.); William Verplank (IDEO Product Dev., U.S.); Eric Werner (PLATO Co., Germany); and Richard Young (Medical Research Council, U.K.). In addition, 13 Japanese speakers gave papers. It was the second international meeting after the first one at the start of the FRIEND21 project in September 1988. Papers were presented in the following sections: Status of the FRIEND21 Project, Communication and Human Interface, Cognitive Models, Interface Design, Communication and Cooperation, Computer-Supported Cooperative Work, and Multimedia.

FRIEND21, as a MITI project, is pursued within a central institution, the Institution for Personalized Environment (PIE), which is in contact with the 14 sponsoring companies (computer manufacturers, home electronic corporations, and publishing or printing companies). At the institute, which is staffed with a dozen researchers, a prototype human interface (HI) is under development, targeting the untrained casual user rather than the professional. The key developers at PIE, Hirotada Ueda (PIE/Hitachi) and Hajime Nonogaki (until recently at PIE and now back at Fujitsu), presented their model: agents (including the human user) for different tasks, which exchange messages through a "studio." For presentation of and access to information, three metaphors, "newspaper," "TV/video tape recorder," and "database," are explored.

Broader aspects of HI were taken up in the other papers presented at the symposium. Hiroshi Ishii (NTT Human Interface Laboratories) presented his concept of an open shared workspace, intending to overcome acceptance problems by not forcing users in a completely new environment. To make best use of the limited screen space, translucent overlay of individual workspace images was introduced. With this overlay technology, the actual faces of the participants could be shown. Prof. Yuzuru Tanaka (Hokkaido University) explained ideas, partly based on Tsichritzis' object-oriented proposals, for open systems. He showed an impressive video of his "IntelligentPad" system, which relies on a generic toolkit, synthetic programming, open platform, and integrated management. His objects could be easily combined, cut into pieces, rearranged, etc. His examples included also an application to computer-aided instruction (CAI) in classical mechanics. Two companies presented results in the field of accessing multimedia. Miyatake (PIE/Hitachi) showed a well-advanced digitized video tape editor that includes automatic shot separation, iconization, and editing tools. Watanabe (PIE/Sony) explained automatic shot separation and investigations of TV quiz programs for development of scenario-based interfaces.

The final panel discussion on "Human Interface in the Future" was led by Prof. Mario Tokoro (Keio University, Sony). In his introduction he gave the picture of a "sea of computers" where everybody can move freely, contacting everybody else with a pocket-size computer. Other panelists gave less futuristic examples and actually the discussion went back to the question, What position should computers have within the society? Two approaches were apparent. (1) making computers useful for everybody, and (2) looking

for needs to support or replace human activities by computers. Both approaches are leading at the end to marketing strategies, problems which are best solved within or together with companies. Philosopher Shun Tsuchiya (Chiba University) came to the conclusion that, rather than worrying about interfaces, school education should provide children at an early stage with knowledge about their own responsibility when using computers. Computers may be faulty or may invite infringements on personal data, copyright material etc.

This symposium was well organized by the people behind FRIEND21 working at PIE, who brought together researchers from various fields and countries and did not avoid critical contributions. PIE is a good platform for discussion and coordination of research on HI related issues. Its own research must be seen as homework to be done within quite a strict budget and time restrictions.--*Ulrich Wattenberg, GMD*

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PACIFIC RIM FAULT TOLERANT SYSTEMS INTERNATIONAL SYMPOSIUM

A summary of the 2-day Pacific Rim Fault Tolerant Systems Symposium, held from 26-27 September 1991 in Kawasaki, Japan, is given.

by David K. Kahaner and D.M. Blough

INTRODUCTION

Computer systems fail. This is either a minor annoyance or a major disaster, depending on the circumstances. For most scientists it is the former, although it can also be a personal disaster if needed data are lost. But for large financial, communication, and military systems, computer failures can have national and even international implications. These days, transferring money means transferring bytes; the recent AT&T failure in the New York area also illustrates just how dependent we are on computing systems. As computing becomes more distributed, there is greater likelihood that some parts will fail, and thus there is a greater need to understand how and why in order to increase the reliability of computers.

In September 1991, 90 scientists from 13 countries met in Kawasaki to share ideas at the 1991 Pacific Rim Fault Tolerant Systems (PRFTS) Symposium. The distribution of attendees was as follows: Japan (59); China (14); United States (7); Australia (3); Korea (2); India, Taiwan, France, Sweden, Germany, Poland, and the United Kingdom (1 each).

Sixty papers were submitted from 14 countries and 40 were selected for presentation and inclusion in the Proceedings. The distribution of submitted papers is very interesting: China (22), Japan (17), United States (5), India (3), Australia (2), Taiwan (2), Korea (2), Hong Kong (1), Canada (1), European Communities (EC) [5 countries] (5).

The Honorary Chair of the meeting was

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The General Chair was Prof. Sachio Naito of Nagaoka University of Technology, which is in Niigata, on the north (Sea of Japan) coast. The program committee has prepared a complete Proceedings of the conference (in English) published by

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There is now no known way to make a computer system entirely fail-safe. By "fault tolerant system" we mean one that employs a class of technologies that reduce the likelihood a system will fail. The techniques fall into two general classes.

(1) Hardware--making the hardware more reliable and rugged, for example, by making it capable of taking abuse or extreme environmental conditions. This includes redundancy in components such as power supplies, disk drives, memories, CPUs, etc. (It goes without saying that there is continual improvement in basic system component design and manufacture.) Of course, redundant hardware is also not new. Initially, computers were so unreliable that some early systems were designed with three units whose results were polled after each operation--the majority determining the output. These days generalizations of this idea are called "consensus recovery blocks." In research, there is work on how to allocate a small number of spare parts such as processors to make them optimally available and economically producible. This leads to some interesting problems in graph theory. Very early work was on error detecting and correcting codes for data transmission. There is still plenty of research going on here. Building in reliability is obviously not limited to special computers. Even many "conventional" systems include UPS (uninterrupted power supply), which is usually a battery or generator back-up.

(2) Software--making the software more reliable. This includes designing/testing out software bugs and also allowing the software to survive even if the hardware fails. Some theory is being developed on how to design operating system software that is more reliable, but there is no fundamental theory. Most researchers on fault tolerant software are probably referring to system rather than application software.

There is general agreement that (2) is the more difficult. Because hardware failures are often more or less random, hardware redundancy is usually successful in improving reliability. But experience with software has shown that the technique of having several people write a program for the same task (N-version programming) often does not improve the overall reliability of the system. In fact, one expert has remarked that it was better to reduce the specificity of the programming task to avoid having distinct programmers make the same error. Using more than one language is another approach, but this leads to other difficulties related to cross language execution.

Several commercial computer systems, notably Stratus and Tandem from the United States, market systems that combine redundant hardware with software that is capable of surviving many different kinds of hardware failures. These companies have been very successful in marketing products here in Japan.

SYMPOSIUM DETAILS

One member of the PRFTS program committee, Prof. D.M. Blough (University of California at Irvine) [blough@sunset.eng.uci.edu] has provided a summary of several papers of interest to him, and this summary is included as an appendix to this article with my sincere appreciation for his efforts. My own comments are immediately below. I was particularly interested in the following.

(1) The large participation by scientists from China, most of whom gave papers on very specific systems they were developing.

(2) An excellent summary of fault tolerant (FT) systems in China, presented by Prof. Shiyi Xu, of Shanghai University of Science and Technology, including more than a dozen references. [Xu has spent time at the State University of New York (SUNY) at Binghamton, as well as Carnegie Mellon University (CMU), and his English is excellent.] He explained that the Chinese recognize the importance of FT systems, and outside of Japan China is probably the only Asian country to have developed FT systems on their own including a triple redundant one for spaceflight use. Nevertheless, Xu commented that there is at the moment no plan to produce a practical nonstop system along the lines of Tandem or Stratus, and that most of the FT work is research only. However, some of these research projects are quite advanced, such as Wuhan Digital Engineering Institute's 980FT86 system. This is based on a multibus hardware model. This system operates in either a multiprocessor or fault tolerant mode and has a failure rate that is simulated to be three orders of magnitude less than for a conventional system. Also, the Chinese have developed some practical software to test programmable logic arrays and this has been offered to foreign companies such as Fujitsu. Xu's paper is also summarized by Blough. Finally, the Chinese have proposed having the 1993 PRFTS in Shenzhen during 5-7 August 1993. For further information, correspond with

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In the United States, the program co-chair is Prof. Ravi K. Iyer, University of Illinois at Urbana-Champaign.

(3) The description of Fujitsu's new Sure system 2000 fault tolerant computer, again summarized by Blough.

(4) Among the other technical papers, I was impressed with a description of C3, a connection network for reconfiguration at the chip design level (wafer scale integration) by T. McDonald (University of Newcastle, Australia) and another by K. Kawashima (Osaka University, Japan) on spare channel assignment in optical fiber networks. In particular, in the latter, the authors claim to have solved an integer LP (linear programming) problem in polynomial time.

(5) One paper was presented by a substitute speaker (K. Forward, Australia) who was not one of the authors. In terms of audience understanding of the paper's key ideas and critical appraisal of the work, this was probably the best presentation at the symposium. Hats off to Prof. Forward. Too bad this technique isn't used more often.

David K. Kahaner joined the staff of the Office of Naval Research Asian Office as a specialist in scientific computing in November 1989. He obtained his Ph.D. in applied mathematics from Stevens Institute of Technology in 1968. From 1978 until 1989 Dr. Kahaner was a group leader in the Center for Computing and Applied Mathematics at the National Institute of Standards and Technology, formerly the National Bureau of Standards. He was responsible for scientific software development on both large and small computers. From 1968 until 1979 he was in the Computing Division at Los Alamos National Laboratory. Dr. Kahaner is the author of two books and more than 50 research papers. He also edits a column on scientific applications of computers for the Society of Industrial and Applied Mathematics. His major research interests are in the development of algorithms and associated software. His programs for solution of differential equations, evaluation of integrals, random numbers, and others are used worldwide in many scientific computing laboratories. Dr. Kahaner's electronic mail address is: kahaner@xroads.cc.u-tokyo.ac.jp.

Douglas M. Blough received a B.S. degree in electrical engineering and M.S. and Ph.D. degrees in computer science from The Johns Hopkins University, Baltimore, MD, in 1984, 1986, and 1988, respectively. Since 1988, he has been with the Department of Electrical and Computer Engineering, University of California, Irvine, where he is currently Assistant Professor. In 1989, he received a joint appointment as Assistant Professor of Information and Computer Science at UC Irvine. His research interests include fault-tolerant computing, computer architecture, and parallel processing. Dr. Blough is a member of Eta Kappa Nu, Tau Beta Pi, the Institute of Electrical and Electronics Engineers, and the Association for Computing Machinery.

Appendix

BLOUGH'S COMMENTS ON PRFTS '91 AND TECHNICAL TOURS

CONFERENCE PRESENTATIONS

The opening presentation was an invited talk delivered by Prof. Shiyi Xu of Shanghai University of Science and Technology. The presentation was titled "Fault-Tolerant Systems in China." Dr. Xu gave an overview of the research being carried out in fault tolerant computing and testing in China. Recently, China has begun to emphasize fault tolerant computing. A national conference on fault tolerant computing was begun in 1985 and has been held every 2 years since its inception. A technical committee on fault tolerant computing was formed in 1991. As for the research, it is apparent that China is far behind the United States, Japan, and Europe. The bulk of the work appears to be in the area of testing, where some good results have been achieved. In the area of fault tolerant systems, there have been a fair number of systems designed and manufactured for various applications. All of these systems use standard fault tolerance techniques that have been known for many years. There were no truly experimental systems presented. The most advanced system is the SWI system that was built by an unnamed defense company for an unidentified application. This system uses self-checking and real-time monitoring techniques and has a multilevel recovery mechanism consisting of error-correcting codes, operation retry, dynamic reconfiguration, and system recovery. I was somewhat disappointed by the small amount of work being done in fault tolerant systems theory and software fault tolerance, areas in which research does not require tremendous resources.

Prof. Shyan-Ming Yuan of the Department of Computer and Information Science of the National Chiao Tung University of Taiwan delivered a presentation titled "An O(N log^2 N) Fault-Tolerant Decentralized Commit Protocol." This was a very nice piece of work concerning the problem of implementing an atomic transaction mechanism in a distributed database system that is subject to node failures. The author had previously proven that any decentralized commit protocol without failures requires at least on the order of N log N messages. In this presentation, an algorithm was given that can tolerate up to (log_2 N) - 2 faults using O(N log^2 N) messages. The algorithm utilizes a supercube communication structure to perform the protocol. It has the desirable property that a transaction will be aborted only if some nodes want to abort the transaction or if some node fails before making a decision to commit or abort.

A paper titled "Fault-Tolerant Attribute Evaluation in Distributed Software Environments" by Feng, Kikuno, and Torii of Osaka University, Japan, dealt with the tolerance of workstation outages in multistation software development environments. In such environments, software developers combine to design large software packages using multiple workstations. Modules developed on one workstation often need to interface with modules developed on another station, meaning that workstation outages can significantly decrease productivity. In the proposed approach, redundant information concerning the modules on other workstations is stored in a data structure called an interface graph. The paper shows how this redundant information can be used to allow one workstation to receive semantic information concerning software modules on another workstation even if that workstation is inaccessible.

A very interesting presentation was given by Mr. Hiroshi Yoshida of Fujitsu Ltd. titled "Fault Tolerance Assurance Methodology of the SXO Operating System for Continuous Operation." In this presentation, we were exposed to the operating system for the SURE SYSTEM 2000 computer, which is Fujitsu's new entry into the fault tolerant computing marketplace. [The printed paper focused entirely on the operating system, SXO (SURE System 2000 Expandable Operating System), but the author also gave a very brief description of the hardware, which is built around two buses and is scalable up to six processor modules.] The presentation described the process through which Fujitsu designed, manufactured, and tested the SXO operating system in order to assure its software fault tolerance capability. The process consisted of exhaustive listing of error symptoms, construction of a recovery process chart that explicitly details the steps taken to detect and recover from each error symptom, identification and careful design of critical routes that could lead to system failure, and testing through artificial software fault injection. While this process was thoroughly and carefully implemented, there are several problems with the general approach that were brought up during the discussion following the presentation. The first problem deals with the reliance on an exhaustive listing of error symptoms. The number of error symptoms that could occur in such a system is virtually unlimited.

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Since only the listed symptoms are detected, unanticipated errors will not be detected and could cause system failure. The second problem is that there is no recovery from recovery failures. In other words, if a fault occurs during the process of recovering from a fault, the system could fail. This problem was recognized by Fujitsu and led to the definition of a critical route, i.e., any procedure whose failure would lead to a recovery failure. The design team took special care to inspect these critical routes, reduce their number, and simplify their design. It is safe to say that the measures described in the paper will serve to greatly increase the reliability of the SXO operating system. There is still a good chance, however, that unanticipated bugs will cause system failure or seriously impaired performance in the early stages of system life. [One attendee from Tandem pointed out to me that one of the important features of Fujitsu's system was the incorporation of an artificial fault generation mechanism built into the operating system. Each SXO component can have 10 or more interrupt points, and several thousand have been built in already. The final product can be shipped with the traps embedded but not in operation. In this form there is negligible overhead, but it is very easy to bring them into effect. Traps are written as C macros, and hence are easy to program. DKK]

TECHNICAL TOURS

At Fujitsu, we were shown the new Fujitsu parallel computer, called the AP1000. Fujitsu has produced a small number of machines of this type ranging from 64 processors to 512 processors. These machines are used inside Fujitsu and at various universities in Japan and other countries for parallel processing research. At this time, Fujitsu has no plans to try to market this computer. Highlights of the AP1000 architecture include three communication networks, nodes composed of SPARC processors with Weitek floating point co-processors, and a very fast interprocessor communication mechanism. The three networks consist of one for broadcasting to the nodes from either the host or another node, one to handle barrier synchronization, and a third for interprocessor point-to-point communication. The point-to-point communication network has a torus configuration and the routing algorithm combines wormhole routing with a structured buffer pool approach to avoid deadlock. The Fujitsu representative reported that they had achieved a processing rate in the range of 2-3 GFLOPS using their 512-processor machine on the LINPACK benchmark. This places the AP1000 below both the Intel Delta machine and the Thinking Machines Connection Machine. The lower performance as compared to the Delta machine probably results mainly from the performance difference between the SPARC processor with a Weitek floating point co-processor used by the AP1000 and the Intel i860 used by the Delta machine. I should mention that the AP1000 possesses no fault tolerance features. Fujitsu has also recently developed a fault tolerant computer called the SURE SYSTEM 2000, but we were not shown anything related to this machine during the tour.

The second stop on the tour was at a Hitachi research laboratory specializing in expert systems. Here, we were shown a videotape detailing the development and use of a Hitachi expert system for planning construction of large tunnels. We were also shown statistics concerning the numbers of expert systems in place at 261 Japanese companies. The data showed the percentages of these systems that were diagnostic type (about 40%), planning type (about 27%), design type (about 16%), control type (about 6%), and other (about 11%). Again, we were not shown anything related to fault tolerant computing.

PARALLEL PROCESSOR FOR MANY-BODY CALCULATIONS, GRAPE

Project GRAPE, a parallel computer for many-body calculations, which was developed at the University of Tokyo, is summarized. The current version operates at 10 GFLOPS.

by David K. Kahaner

INTRODUCTION

Classical many-body systems play a key role in astrophysics, star clusters, galaxies, and clusters of galaxies when their interactions are described as a system of particles interacting through gravity. At the other end of the mass spectrum, plasmas and systems of molecules are also treated as many-body systems that interact through Coulomb and van der Waals force. In astrophysics, the applications are primarily to basic science, but at the molecular level applications are to drugs, smart material design, and many other practical problems.

The basic idea is very simple: a large collection of particles start at an initial configuration and interact with each other according to Newton's law, the acceleration of each particle determined by the forces acting on it, those generated by the other particles, and any other external forces. The detailed form of the force between two particles is determined by the system but depends nonlinearly on the distance between them. (The major assumption here is that the particles are point masses.) This leads to a system of N second order ordinary differential equations (if there are N particles), all of them looking very much alike.

In the simulation of these systems one thus needs to solve the equations and their solution will describe the subsequent motion of the particles as time progresses. In principle this is very simple; the differential equations are solved numerically by taking finite, but small, time steps. At each time step the forces are computed and the particles moved an appropriate distance. If there are N particles, there are N^2 force interactions that need to be computed, usually by pairwise summation. For large systems this portion dominates all other aspects of the computation, as the time for other parts is usually linearly dependent on N.

N-body computations are one of the major absorbers of supercomputer cycles. For example, at the Australian National University the two scientific fields using the most supercomputer time during 1990 were astrophysics and molecular dynamics [see D.K Kahaner, "Computing and Related Science in Australia," 16(4), 47-68 (1991)]. Most of this was for N-body calculations. For example, one 2,000-body simulation on a Fujitsu VP-400 took 40 hours, although very clever algorithms can reduce this. Molecular dynamics simulations are extensively used to study three-dimensional structures of protein molecules and the phase transition of materials.

The basic calculation is inherently parallel. Many clever techniques have been developed to speed up these calculations including extremely sophisticated data structures for linking information about the particles and the use of fast algorithms. For example, in some situations forces die off rapidly with distance, and so it is only necessary to compute the effect of nearby particles. Thus particles could be grouped into near and distant, leading to efficient algorithms. For short-range force problems of this type, linked-list algorithms can reduce the force calculation to something proportional to N. Tree algorithms can be used in those cases when the required accuracy need not be very high. These latter algorithms can be quite complicated and might be difficult to program on fine grained supercomputers, although the amount of computational work can be reduced from about N^2 to about N*ln(N) for the force calculation. For example, a force calculation for the i-th particle could be written as (a cell is a collection of nearby particles)

```
subroutine treeforce(i,cell)
if( cell and particle i are well separated )
   force = force from the center of mass
      of cell
else
   force = sum of forces from the
      children of cell
endif
end
```

Of course, this has to be implemented either in a language allowing recursion

or in Fortran by an appropriate data list.

For systems on a uniform spatial mesh, fast Fourier transform (FFT) methods can also be applied. FFT algorithms also reduce computation from N^2 to N*ln(N) and can be very effective, but they only work with a uniform mesh. There is still a limit of a few tens of thousands on the number of particles that can be easily dealt with. The number of atoms in a large protein molecule exceeds 10,000, and when immersed in water the system can easily exceed 100,000 particles. Direct pairwise summation of the forces can lead to excessive computation but is very general and applicable to virtually any physical structure.

GRAPE

GRAPE (GRAvity PipE) is the name for a series of special purpose parallel computers designed at the University of Tokyo by

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The GRAPE project (GRAPE-1, GRAPE-1A, GRAPE-2, GRAPE-2A, GRAPE-3, and GRAPE-4) has been evolving only over the past 3 years. This is a university project that has had collaborative assistance and hardware support from Fuji-Xerox (just in case you thought that they only built copiers). GRAPE-3 is complete and Makino states that its effective speed is 10 GFLOPS. A series of papers, in English, has been submitted (to mostly physics and astronomy journals) and some papers have already appeared. A bibliography is included below. (Most of these papers have multiple authors, including at least Sugimoto or Makino; thus, authors' names are omitted.) GRAPE is known in the astronomy community. In fact, Makino has just returned from a substantial visit to the Cambridge Institute of Astronomy. But it is not well known otherwise, perhaps because, until recently, the major applications of the project have been to astronomical rather than molecular systems. Because so many of the project's papers are in English, and also since the principals are easily available via E-mail, the purpose of my report is to briefly summarize the history and current status of the project.

The fundamental idea behind GRAPE is that direct summation of forces is simple and parallel. Very excellent work in this area has been demonstrated by users of Connection Machine, but the GRAPE view is that with the advent of VLSI it ought to be possible to build a special purpose chip of modest cost which is still flexible ENOUGH. This is not the only project with this goal. The Delft Molecular Dynamics Processor (DMDP) is specifically designed for these problems, too. The major difference is that Delft's machine does all the computations, while GRAPE systems only perform the force computation. The latter allows much simpler hardware and software. (The fact that the first design for GRAPE-1 began in April 1989, and there is already a machine running at 10 GFLOPS, is a pretty good endorsement of this approach.) The hardware only performs one function; the software is simple to interface with existing Fortran or C. GRAPE is attached to a Unix host by a VME bus (the earliest version used an IEEE-488 interface). The host sends the particles' positions to GRAPE, which calculates the force on any requested particle and sends this back to the host. The total user documentation is available as a few "man" pages. (I have read several examples of GRAPE programs; most users will be able to write their own applications with very little "spin-up" time.) Of course, this means that to some extent performance of a GRAPE system is limited by the host and the communications, while this is not the case for DMDP. For molecular forces, the force computation is less expensive (because only nearby particles need be considered), and thus GRAPE will be less appropriate than DMDP, but for long range forces the opposite will be true. Nevertheless, when costs are considered, GRAPE might be a good choice for either.

The sequence of GRAPE systems shows clearly the evolution of the scientists' thinking about applications, as well as the availability of better hardware. GRAPE-1, -1A, and -3 are "low accuracy." Subtraction between position coordinates is in fixed point using 16, 16, and 20 bits, respectively. Accumulation of the force is 48, 48, and 56 bits, respectively. In GRAPE-2 and -2A, subtraction between coordinates and force accumulation is 64-bit floating point (double precision), while the remainder of the calculation is single precision. The GRAPE-3 system uses a custom LSI chip; up to 48 chips (strictly speaking, 46 chips for the force calculation) can be installed, allowing force calculation on a similar number of particles, in parallel. At a 10-MHz clock, GRAPE-3 can perform about 300 MFLOPS for each chip, thus about

13.8 GFLOPS when fully configured. The full system is in operation now and the measured speed is at present 9.9 GFLOPS. Newer machines have clever pipelining, calculate not only the force but also the potential, use interpolation tables for forces, etc. They also can implement some tree algorithms. A great deal of detail concerning the hardware of GRAPE systems is given in the papers listed below, so we omit this here. Figures 1 through 6 illustrate different GRAPE systems.

Current plans are to develop GRAPE-4, which is targeted at 1 TFLOP. This will be done by using 1,024 1-GFLOP chips in a three-level tree. The host is connected to four controller boards and each board is connected to 16 processor boards, each with 16 pipeline chips on it. The processor board is similar to that of GRAPE-3's, but the wordlength will be increased to allow higher accuracy calculations. The designers hope that the entire package will consume about 5 to 10 kW and thus will be air cooled. They estimate it will cost about $2M to build.

COMMENT

GRAPE systems were designed mostly by astronomers who have real problems to solve. In some way their approach is ad hoc, but they have taken this to the stage where new science is being done daily. It is a very impressive job and it will be interesting to see how well the systems work on molecular dynamics problems.

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"A special-purpose N-body machine GRAPE-1," *Computer Physics Comm* 60, 187-194 (1990).

"GRAPE-1A: Special-purpose computer for N-body simulation with tree code," to appear in *PASJ* (1991).

"GRAPE-3: Highly parallelized special-purpose computer for gravitational many-body simulations," to appear in *HICSS-25*, 25th Hawaii International Conference on System Sciences, Koloa, Hawaii, 7-11 January 1992.

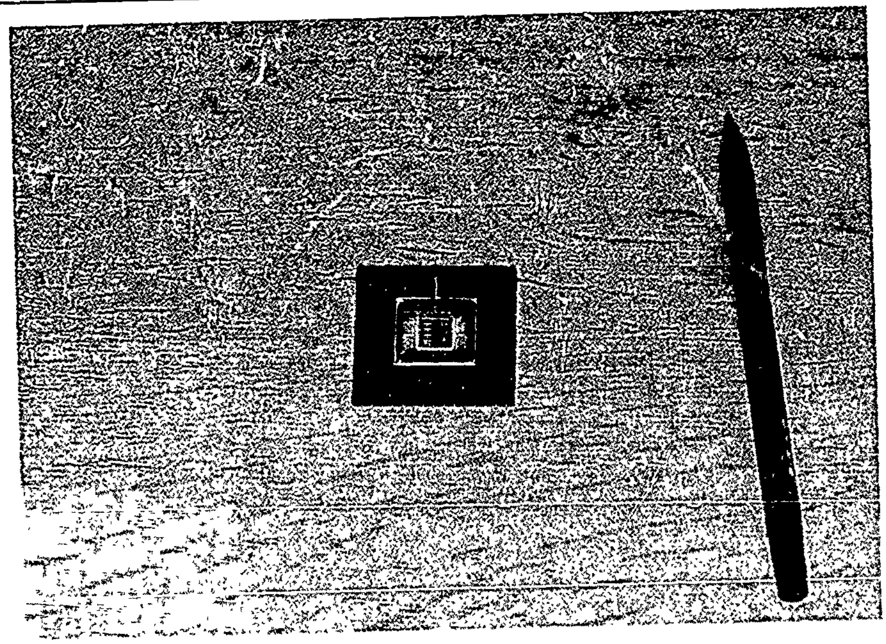

Figure 1. GRAPE chip.

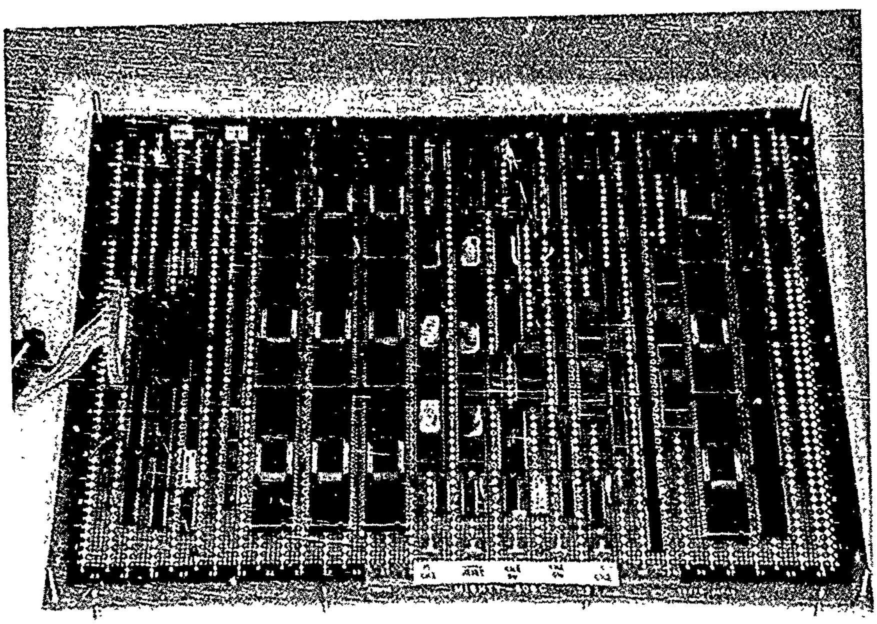

Figure 2. GRAPE-1.

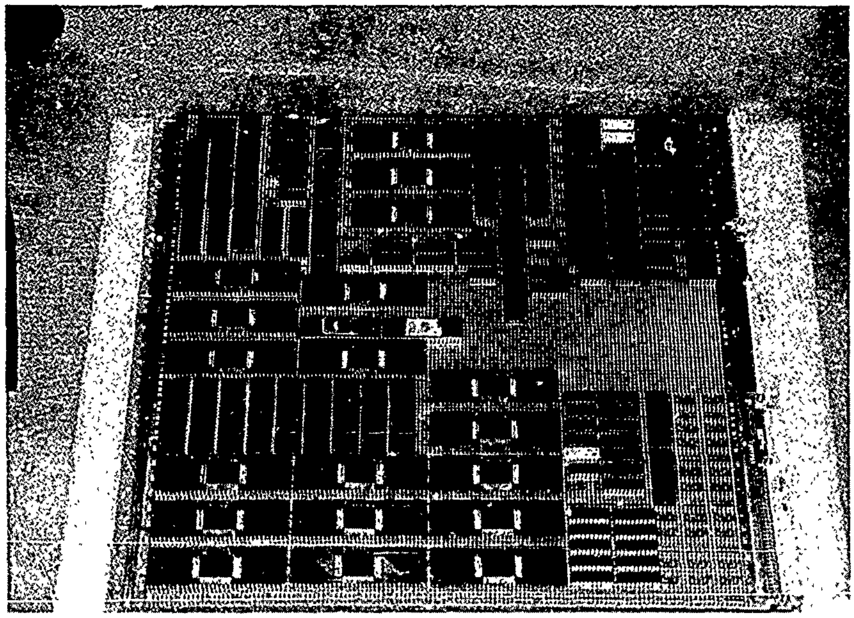

Figure 3. GRAPE-1A.

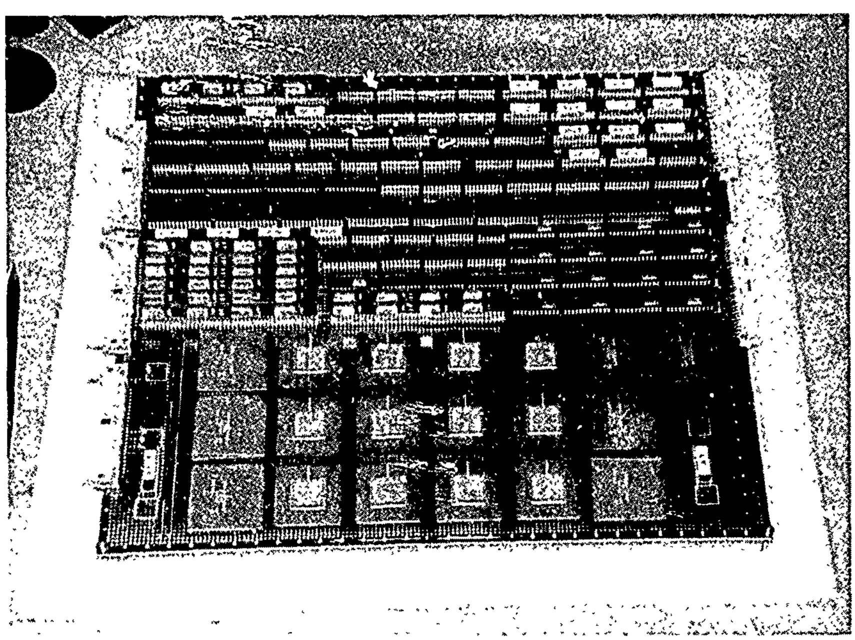

Figure 4. GRAPE-2A.

Figure 5. GRAPE-3.

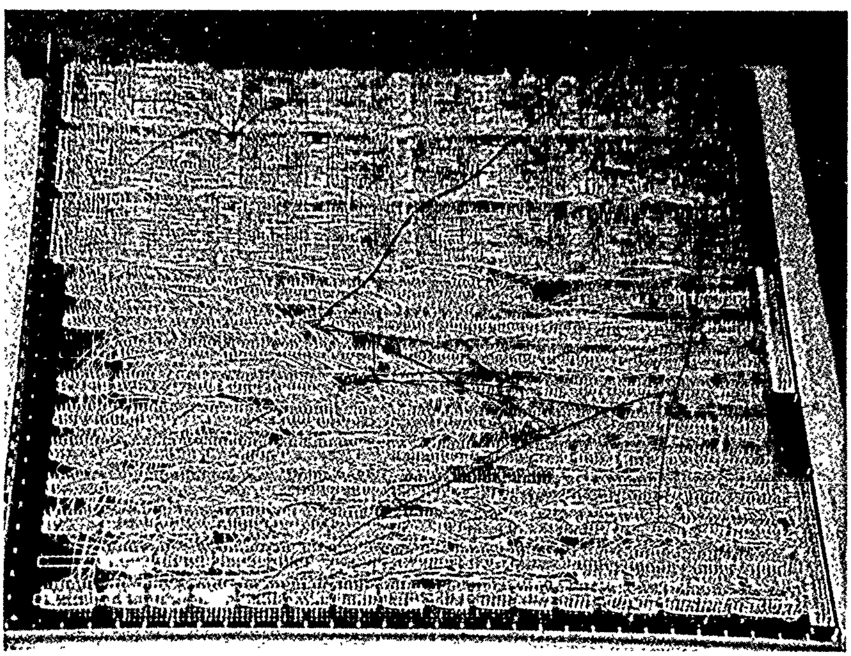

Figure 6. GRAPE-3 (bottom view).

COMPUTER WORLD '91

The international symposium Computer World '91, held in Osaka, Japan, from 24-26 September 1991, is summarized.

by David K. Kahaner

INTRODUCTION

Since 1986 an annual international symposium is held in the Kansai area of Japan under the name "Computer World 'xx"--even years in Kobe, odd years in Osaka. The general idea of these is to promote computer usage and make various first-hand developments accessible to the community at large. This year's CW '91 was sponsored by the Osaka Government, the Ministry of International Trade and Industry (MITI), and the Kansai Institute of Information Systems. Support was also provided by the Japan Keirin Association through its Machine Industry Promotion Funds; these funds are part of the profits that the association had obtained from the sponsoring of bicycle races in Japan. The symposium is also held as part of Japan's information month (September). This year's theme was Multimedia Technology and Artificial Intelligence, with the subgoal of making computers more friendly to people. The symposium was held at Osaka's International House, a beautiful, modern facility with large convention exhibit and lecture space.

Osaka is to Tokyo very much what Chicago is to New York, its Midwestern manufacturing heart. Like Chicagoans, Osakans are very proud of their accomplishments, but they also have a slightly defensive stance when comparing cities. Osaka is also the major city in Japan's Kansai area. It already has an international airport, but the new Kansai airport, in the bay, will become a major siphon for visitors. The Japanese Government, well aware of the problems with congested Tokyo, is trying (at least on paper) to decentralize itself. While there are 3.5 million Japanese living in Osaka, it is much less congested than Tokyo, and like citizens of Chicago, Osaka's citizens claim that they are more human, more civilized, their food is more sophisticated, their language is more refined, their women are more attractive, etc., than those in Tokyo.

My invitation to attend was from the program chairman,

Prof. Seiji Inokuchi
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whom I had met at an earlier meeting. Prof. Inokuchi's interests are in three-dimensional (3D) vision systems, and one of his systems is used at the National Aeronautics and Space Administration (NASA) in the United States.

Also attending many of the sessions was

Mr. Christfried Webers
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My thanks to both Inokuchi and Webers for their valuable additions to this report.

The general chairman of the organizing committee was

Dr. Tetsuro Kawakami
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Considering the size of the organization that he manages, it seemed really remarkable to me that Dr. Kawakami actually attended many of the symposium sessions.

The CW '91 symposium combined about two dozen lectures in two parallel sessions and also a small vendor exhibit. Exhibitors were mostly Japanese vendors demonstrating artificial intelligence (AI) type software products;

one of the most interesting was Fujitsu's (see below). About two dozen Westerners were in attendance; most of these presented invited rather than submitted lectures. Simultaneous Japanese/English translation was available. In the past I have been disappointed with the quality of such translations, but in this case the translators really did an outstanding job, and I believe that very little was misunderstood.

Total attendance was a few hundred. This was below the expectations of the organizers, who claimed that there were several other competing conferences during the same week. By Tokyo standards attendance was very low. Last year's supercomputing symposium drew several thousand, at least to gawk. I attribute this low turnout mostly to the much more modest exhibit venue, and also to the fairly technical content of the papers. This symposium has positioned itself about halfway between a highly specialized technical meeting and an exhibition. There were interesting papers presented on a variety of topics related to advanced use of computers. Everyone could find something to listen to and appreciate, but at the same time the wide range meant that it was not possible to glean any significant national trends except the obvious ones that computers are getting more sophisticated, more entwined into our culture, and more user friendly. Almost all the papers were overviews, ranging from economic prospects in the European Community (EC) to network capabilities in Japan; thus, researchers could get an excellent picture of a large part of some field but probably wouldn't learn much about very new results that were not already being communicated through more specialized channels--in short, an excellent opportunity to learn about one or more new fields but perhaps not quite so good to learn about new results in your field.

The symposium has released a Proceedings with papers, some in Japanese. Copies are available by contacting

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SUMMARY COMMENTS

In a recent report [D.K. Kahaner, "Virtual Reality," *Scientific Information Bulletin* 16(4), 43-45 (1991)] I already mentioned eye tracking research at ATR and virtual reality activities at the University of Washington, both papers presented here at CW '91.

M. Cooley (FAST, Brussels) gave a mesmerizing opening talk about the implications of technology, generally, and computing, specifically, on countries within Europe. I won't either summarize or comment on his Europe-related remarks as my focus is Asia (his paper is given in the Proceedings). However, with respect to the more AI related material, Cooley pointed out the need for more anthropomorphic systems, for expert systems that support rather than replace humans, and for systems that reduce the cultural imperialism of English; the need to free designers from menu-driven systems; the necessity of getting out from under our obsession with rule-based systems; a refocus on education rather than training; and overall more emphasis on human-centered systems. He ended by saying,

> It is a profound responsibility of all those involved to ensure that we develop forms of science and technology which will help to heal a wounded planet, which will address the issues of drought, poverty, and suffering worldwide and will develop sustainable systems and products which lay the basis for the form of society we wish to see as we enter the 21st century.

Many later speakers echoed his remarks in their own terms.

For me, the most inspiring paper was presented by K. Kikue (NHK) describing an experiment with sixth graders (12 years old) at a Japanese public school. NHK has prepared a 15-minute high definition television (HDTV) program showing how industrial progress has destroyed the forests in Japan. There is also an HDTV textbook containing photographs electronically printed in HDTV and a multimedia workstation. Using this workstation, the students (in small groups) prepared multimedia presentations about environmental issues, splicing in visual and sound bits from NHK's and their own materials in whatever order seemed appropriate to them. The sophisticated workstation software includes image menus and allows the students to edit image and sound from a laser-disk and also video tape that they shot themselves. Kikue showed a video taken of the students working together on their projects and then presenting them in NHK's "future classroom." The latter was filled with students, faculty, and parents watching their kids. Anybody who doubts that people will pay for HDTV should watch this video to absorb the excitement and enthusiasm of these children and then ask themselves if these 12 year olds will be satisfied with lesser technology as they grow into consumers.

Researchers from Fujitsu described a new AI environment developed in Japan and only available (at the moment for Fujitsu systems) built with the following requirements in mind.

- The knowledge processing system should be efficiently built and available to use within the language culture of conventional systems.

- It should be efficient and resource saving.

- It should express, handle, and control various kinds of complicated knowledge that differ from a simple set of rules.

- It should have a simple and easy to use front end.

Lest you think this is just for computer scientists, object Fortran has arrived. Enter Fujitsu's Fortran/KR (knowledge reasoning). This allows rules, objects, event-driven, fuzzy techniques, Dempster-Shafer, and neural techniques. Fujitsu has begun shipping a development environment and object-oriented user interface. (I hope to see a demonstration of this and will report further at that time.)

K. Tanaka (Kobe University) gave an overview lecture on the developing methodology in database (DB), beginning with hierarchical (CODASYL), moving to relational (RDB), then to object-oriented (OODBMS). He felt that the use of each is bell-curve-like over time and that now we are at the center of the RDB usage, at the tail-end of CODASYL use, and in the prototype stage for OODBMS usage. He went on to list the advantages he saw in using this new technology.

- Consolidation of various languages (not a special DB language)

- Data model closer to world information

- Better performance, perhaps up to two orders of magnitude

He also mentioned some of the OODBMS applications he knew about.

- Concurrent engineering and computer-aided design/ manufacturing (CAD/CAM)

- Computer-integrated manufacturing (CIM) DB

- Multimedia

- Management information systems (MIS) (now called Strategic Information Systems)

- Knowledge base

Naokazu Yokoya [Electrotechnical Laboratory (ETL), E-mail: yokoya@ etl.go.jp] gave a good survey of new trends in computer vision algorithms. I was very pleasantly surprised to learn that "constraint satisfaction and cooperative algorithms" essentially meant the use of extremely well understood methods in numerical optimization such as regularization, implemented via gradient descent, simulated annealing, or other fairly standard approaches. There was also a discussion of matrix iteration techniques necessary to solve the linearized problems that arise--again mainstream numerical computation.

A more detailed paper surveying research at Osaka University on vision for autonomous mobile robots was presented by Y. Shirai. Their work involves two key ideas: (1) stereo images that are brought into correspondence by iteration and (2) color image segmentation using the brightness and edge histogram, i.e. without considering the semantics of the scene.

There were a number of very interesting advanced application talks including the following.

Akiyoshi and Nishida (Mitsubishi Electric) (E-mail: {akiyoshi}{nishida} @sys.crl.melco.co.jp) are studying the issue of training of large-plant operators in how to cope with emergency situations.

Researchers from Kansai environmental and electric power institutes have developed an expert system to assist tree planting, i.e., to deal with landscaping, soil, vegetation, tree types, etc.

Osaka Gas scientists are developing a speech recognition system. This is becoming mature technology and there is ample work going on in the West, including Carnegie Mellon University (CMU) and other universities. Osaka's application prototypes will be ready this fall to assist gas construction workers in filling out their reports and in digital mapping. My understanding of this work is that it is using well established methods (such as close talk mike, phonetic engine, phonetic codes, two stage decision tree, finite state grammar, etc.) but that it is a complete system, neatly packaged using a DSP5601 acoustic processor in a phonetic engine, hooked by RS232 to a 68020 workstation where the linguistic decoder resides. In other words, it is ready to perform real work.

Y. Hosokawa (Sanyo) gave a detailed description of his company's CD-ROM car navigation system. There are several of these in actual use within Japan. I reported on Sumitomo's last year, which used sophisticated onboard sensors. Sanyo's also uses sensors, but in addition incorporates input from the eight GPS satellites that will be in position by 1992, allowing location precision to 30 meters. (The sensors are needed in cases when the satellites are unavailable, such as in tunnels, near high buildings, etc.) Hosokawa also gives details of the map organization on the CD-ROMs and points out that about 20% of Japan (78% of the population) has already been digitized at a scale of 1:25000, although additional building data are still needed. Development of navigation systems is being supported in Japan by the police and various ministries, including the Ministry of Post and Telephone and the Ministry of Construction. Sanyo's system also permits voice (driver) input for control.

Kenichi Sahara (Sumitomo Electric Industries, Ltd.) showed a design environment for graphical user interfaces based on the X Toolkit. Interface objects can be selected from a depository and the interface is constructed without writing explicit code. The interface objects are embedded in editing objects, which act as a glue between the user and the interface. It was interesting that the editing objects can collect information about preferences of the user and therefore accumulate knowledge about the construction of the interface.

Toshie Nakamura (Osaka University) used computers to investigate human perception of music. She found that humans can recognize a crescendo much easier than a decrescendo. Her explanation: In the evolution of humans we have learned that sounds fade out and therefore developed adoption mechanisms. These mechanisms focus on the unusual, fading a decrescendo out while amplifying a crescendo. She also found a relation between the optimum time intervals in music or speech and the breathing and the mental tempo of the listener.

Kazunori Shimamura (NTT Human Interface Laboratories) reported on their research about cooperative works supported by multimedia multipoint telecommunication and introduced the PMTC prototype for B-ISDN that supports up to 20 users. Their survey of 708 Japanese businessmen in 35 companies shows that about 60% of the conferences requiring trips can be substituted by video conferences plus facsimile. They implemented four service concepts into their PMTC prototype. First, the system is for personal use, which means it must be based on a personal workstation. Second, there are virtual conference spaces necessary that can be occupied by a subset of all conference participants. While information from the outside flows into this space, no information flows out. Third, multimedia support (graphics, telewriting, telepointing, and also high quality full motion video and high quality voice transmission) is necessary to exchange intentional and observational information. Fourth, a sophisticated user interface in the form of a multimedia multiwindow display is a must. For the connection they use a mesh type architecture because a star type restricts the way of information exchange. Necessary network speeds are in the range of 155/620 Mbps over multiple logical channels.

Jun Murai (Keio University) gave a talk on WIDE (widely distributed computing environment). WIDE was started in 1987 and has a budget of $600,000. It has contracts with 15 companies, but unlike other countries, it gets little assistance from the Government. It consists of one backbone in Japan that will be backed up over satellite (ISDN class D) starting from June 1992. This backbone connects directly to the Internet. It has 6 network operation centers and connects to 130 networks. There are currently 57 researchers involved in the project. Research focuses on special local characters in net technologies and multicast datagrams. ISDN is studied as a cost effective way to connect computers. Students at the Keio University campus in Fujisawa can already access their network from a public ISDN box at the campus. A project on voice interfaces might lead to system and network administration over public telephones. The person in charge can then access the computer over the phone, get a status report from the computer as voice mail, and give commands to correct a problem. An international conference called INET '92 will be held from 14-17 June 1992 in Kobe. Information is available over E-mail from inet92-info@wide.ac.jp. WIDE itself can be contacted at wide@wide.ac.jp.

INTERNATIONAL CONFERENCE ON COMPUTER-INTEGRATED MANUFACTURING 1991 (ICCIM'91)

The International Conference on Computer-Integrated Manufacturing 1991 (ICCIM'91), held from 30 September to 4 October 1991 in Singapore, is summarized. Singapore manufacturing science activities are focusing on building value-added solutions using modern but well known ideas and equipment and have a very aggressive education/training plan to increase the number of specialists in advanced manufacturing, exactly what is needed for a small country with few natural resources. Also, the Singapore/Japan AI Center and the National University of Singapore are discussed. The AI Center provides significant advantages to both countries.

by David K. Kahaner

INTRODUCTION

The International Conference on Computer-Integrated Manufacturing 1991 (ICCIM'91) brought together almost 250 scientists from 28 countries for a week in Singapore, between 30 September and 4 October 1991. The participant distribution was as follows.

Country	No.
Singapore	135
China	12
Malaysia	10
United Kingdom	8
Australia	7
Indonesia	7
United States	6
Japan	6
Switzerland	5
Sweden	5
Taiwan	5
Italy	4
India	3
Thailand	3
Germany	3
Hong Kong	2
Yugoslavia	2
Poland	2
Denmark	2
Finland	2
New Zealand	1
Romania	1
South Korea	1
Israel	1
France	1
Turkey	1

Surprisingly, there were only a handful of Japanese attendees and almost no Japanese speakers. Either advertising was weak in Japan or the Japanese were unable to attend for other reasons. It may be that some Japanese still see an international conference held in Singapore as not truly of international standard or flavor. Perhaps they thought they could get more exposure or learn more new things by attending international conferences in the West. This would apply equally well to Japanese participation in conferences in other developing countries.

Also, while companies in Japan are more advanced and active in "engineering" research than universities, this is changing very rapidly; their universities are picking it up at a great speed. The recent Japan Intelligent Manufacturing System (IMS) program puts very strong emphasis on university-based research, and joint university/industry projects are a very powerful way to speed up this change. I am told that if one attends international conferences in Europe, for example, there are some very good engineering papers from Japanese universities presented.

Three days of research papers (almost 150 papers in five parallel sessions) were preceded by two days of tutorials in three parallel sessions. (Tutorial speakers from the West were invited and expenses paid to encourage their attendance.) On the last Saturday there was a visit to the GINTIC Institute of CIM on the campus of Nanyang Technological University. Aspects of the tutorials that were most useful were the discussions by Singaporeans of their country's science and technology plans

and especially in the area of manufacturing. I have summarized this material below. The technical papers were the usual mix; a few are discussed below, but as the Proceedings are in English, my emphasis is to focus on those things not readily available. The visit to GINTIC was a tremendous hit by all participants and reinforced some of the points made during the earlier sessions about Singapore's commitment to this technology.

Most of the featured and tutorial sessions were given by Western scientists, including those from the United States [Gerhardt (Rensselaer), Lu (University of Illinois), Biles (University of Louisville), Mills (University of Texas-Arlington), and Tse (Stanford)] and Europe [Gillin (Swinburne Institute of Technology), Sackett (Cranfield Institute of Technology), Ranky (University of Surrey), Weston (Loughborough University of Technology), Nolan (University of Galway), Warschat (Fraunhofer Institute for Industrial Engineering), and Vamos (Hungarian Academy of Sciences)]. The majority of these highlighted talks were about how Western researchers see manufacturing in the next 5 to 10 years. The significant Singaporean exception was the excellent tutorial by

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who has been most helpful in explaining details of Singapore's science directions to me and who also provided a great deal of statistical information for my use. Ho is also a very articulate spokesman for CIM, and people like him are a critical reason for Singapore's current achievements and probable future success.

Generally, the main lectures were by academic experts who have been thinking at a very high level and are primarily concerned with educating and planning, e.g., several papers had subtitles like "Strategic Issues for the '90s," "Is CIM the Right Choice," "Simultaneous Engineering--The Competitive Edge," and these would all make good reading. Within the contributed papers there were a great many descriptions of real automated manufacturing, but most of the papers were still about plans, prototypes, simulation, or fairly small systems. However, some of the plans are for systems that will impact large manufacturing, such as one for production equipment in the Brazilian pulp and paper industry (R.M. Naveiro). There were also several talks on computer supported cooperative work (CSCW), which takes as its primary role the ways in which computer systems interact with people in a joint effort to solve problems. Good discussions of this were given by P.P. Yim (CIM Group) and T. Winograd (Stanford). People in the States and Europe (and even Japan) have been exploring this technology to support engineering teams for several years now. Xerox, Digital, and IBM, for example, have been active in this area. Fuji-Xerox has a division of almost 100 people to work on this technology. The basic idea is to extend the impact of computers on individual productivity gains to group productivity improvements.

Even among the contributed papers there were many addressed primarily to management trying to educate them to the changes needed to support CIM (see, for example, Leong's on "Building a Supporting Manufacturing Infrastructure for CIM"). (Leong lists almost 20 steps.) There were several papers about teaching CIM, the most notable about a master course at the University of Surrey (Ranky) and plans for a computer network for education on CIM in Japan (Kanda et al.). In the area of simulation, I again was treated to a talk about numerical optimization techniques much like one I described in my report on Osaka's Computer World (see page 21). Also, there were several other papers to gladden the hearts of numerical analysts everywhere, including "Numerical Simulation as a Central Element in a CIM System" (H. Groth et al., ETH) and "Computer-Aided Tolerance Chart Balancing" (B. Ann, Singapore), describing the use of linear programming for this application. There was a very good session on standardization of data exchange formats, and a particularly excellent overview paper by M. Davies (CAD-CAM Data Exchange, U.K.). In addition to the expected large number of papers from the West and from Singapore, I should also mention that Taiwan, Korea, and China were well represented. (A very interesting paper describing the Chinese view of CIM was given by J. Xingling, Shanghai, alas, with no references.) I am happy to report also that there were four good papers from scientists at the University of Technology Malaysia, including a wheel wear compensation study and a welding engineer expert system. Perhaps this very poor country will be able to bootstrap its way into modern industrial development. Surprisingly, there were no papers from Indonesia, which is the world's fifth largest as well as the fifth most populous country, has large quantities of oil, and is a neighbor of Singapore.

There was also a small vendor exhibit of about 18 companies, mostly computer-aided design/manufacturing (CAD/CAM) systems, electronic data interchange (EDI) interfaces, robotics applications, artificial intelligence (AI) packages, and related software. About half of these companies were joint ventures between Western and Singaporean companies (e.g., Hewlett-Packard Singapore, IBM, DEC, Sun); the remainder were Singaporean companies showing either their own or Western products. There was also one

Singaporean book publisher, World Scientific. To date most of their books have been in science, but they are moving rapidly into the engineering market.

SUMMARY

This report should be considered as a supplement to my earlier one [D.K. Kahaner, "Computing and Related Scientific Activities in Singapore," *Scientific Information Bulletin* **16**(3), 53-63 (1991)], and so I will not repeat background material.

In addition to the technical details that were reported in depth at this conference, there was also a very clear statement about the future of manufacturing. This was made repeatedly by speakers and audience and should be thought about carefully by everyone concerned with productivity. The term "computer-integrated manufacturing" is already viewed as not correctly describing future directions. Instead, people are talking about "computer-integrated enterprises."

The main difference between CI "manufacturing" and CI "enterprise" is that researchers have now realized the only way to solve manufacturing problems is to take a "system" point of view of the whole production enterprise. Taking a system point of view, however, makes the problems much more difficult. Generally speaking, there are three levels of understanding, event, process, and methodology, before sound solutions are possible. The event level focuses on individual results (or cases) and experiences gained from these results. At the process level, attention is paid to the underlying reasons (e.g., physics, mechanisms, rationales) upon which the events were based. At the methodology level, various models and theories, empirical or analytical, are proposed to explain and guide event occurrences based on the understanding of their respective processes. It is felt that one can only arrive at a sound system solution through a gradual evolution through these consecutive levels of understanding; any deviation within or between these levels will not lead to a useful system solution.

Cutting through the jargon, this means that the manufacturing facility of today should be thought of as one part of a larger organization that includes marketing, planning, designing, scheduling, ordering, and shipping raw materials and products, etc., and of course, the shop floor manufacturing, too. In this context, intelligent or integrated means information flow--making information widely available, using the same information consistently, and moving information rapidly from its source to where it is needed. In other words, we are moving away from the computer numerical controller (CNC) and robot manipulation world that is down on the shop floor, and beyond the purely data intensive, database, CAD/CAM world, to a knowledge intensive decision level where the tools will be much more knowledge processing related, involving AI and other high level computing models. In this world view it is extremely clear the crucial role to be played by computing and associated information technology (IT) fields; information and its flow is seen to be at least as important as welding, grinding, etc. Any company or country that can pull these together was seen by this group as having a large leg-up on those who cannot.

Some interesting contrasting comments were made by scientists within the CIM community. For example, P. Yim asks, "Have manufacturing companies or industries, as a whole, improved through the synergy gain from the past decade's integration efforts for those who opted to invest into computer-integrated manufacturing? The answer [he feels] leans towards NO." I am sure that there would be quite a lot of disagreement with Yim's assessment. However, within the papers presented at ICCIM'91, there was the definite sense of still trying to justify the research, that is, trying to convince others that there is something here more than just ideas. To me this feels very much like the early days of computer science, and if so it will pass in time.

There are two issues to be mentioned about this meeting. The first concerns new ideas in manufacturing research in an absolute sense and the second concerns its state in Singapore.

I believe it is fair to say that Singapore is not developing ideas that are ground breaking. The work that I saw is along very traditional lines using well established concepts and basic directions. There is a substantial amount of education related research and training, and also several interesting potential products that are in progress. Most of this work is centered around the GINTIC Institute of CIM at Nanyang Technological University. A smaller amount is at the National Computer Board's Information Technology Institute. GINTIC and the program to train Singaporeans are very strongly modeled after Western models, such as the programs at Rensselaer and at Fraunhofer. In fact,

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was one of the featured speakers at ICCIM'91, and he has been to Singapore many times. I asked him specifically about research here and he pointed out that while the country has made huge progress over the past 5 years, it is still mostly instituting programs and projects from the West and trying to adapt

them to local needs. However, their expertise is growing rapidly and will allow them to be much more innovative in the future.

A very similar assessment was provided to me by another invited speaker,

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Making these comments about Singaporean developments is in no sense to diminish their accomplishments. Lu pointed out to me that

> Manufacturing is not a science, at least not in a traditional definition of science. Rather, it is a true engineering. The difference here is an important one, because science is often revolutionary and engineering is always evolutionary. I agree that most manufacturing work in Singapore is not earth-shaking, but their persistent and progressive efforts in careful implementations of manufacturing technologies are, to my judgment, the right way to deal with manufacturing engineering.

Further cooperation between GINTIC and Western scientists is also in the offing. Lu also told me that he is discussing the possibility of transferring one of the machine learning system developed in his Illinois laboratory to GINTIC for pre-production enhance ments.

A very substantial fraction of the papers presented at ICCIM'91 were written by Singaporeans, often about real problems. If the papers do not address grand challenges, then at least their proposed solutions and approaches are current and competitive. They are actively trying most of the techniques that are being discussed within the manufacturing science community today. (This is not surprising, as almost all Singaporean senior scientists have in-depth knowledge of Western approaches and in most cases have visited or studied at U.K., U.S., or other leading universities.) Furthermore, visitors to GINTIC were all extremely impressed, and if these accomplishments are judged by regional standards, the results are even more impressive. The country is trying to develop value-added solutions and perform enough focused research to make their own products more efficient, cost effective, or both. For example, we were shown a track following robot at GINTIC. The robot is built with perfectly standard technology, and if it was observed in a section of a U.S. or Japanese factory, it would have been totally unremarkable. In fact, it still had a few minor glitches. The interesting thing here was that it was entirely designed and built by a class at the university. Similarly impressive is the large amount of equipment that is available for experimentation (including a stereolithography unit), although this has all been purchased from Japanese, U.S., or European Community (EC) suppliers. (However, see the comments below in the National University of Singapore (NUS) section on potential problems.) This view of the activities in Singapore was also shared by virtually all the Western attendees at the symposium. Finally, I want to mention that Singaporean scientists are very well read and aware of what is going on elsewhere. The best example of this is their choice of invitees to ICCIM'91, but this was also clear from discussions on the conference floor. They understand the modern principles that are now guiding advanced industry, such as the ten commandments of concurrent engineering, design for assembly, design-build-teams, etc. Of course, like elsewhere, they are not always implemented as well as one would like. They are also well aware of major programs such as the Ministry of International Trade and Industry's (MITI's) IMS, micromachines, and others and participate actively in standard-making organizations. In particular, they see standards are essential to allow them to produce products that can have a large market.

The key ingredients in Singaporean science, as I see it, are focus and coordination. The country has a view of where it wants to go. Essentially all government policy is thus directed toward this goal; it is not so much that general research ideas are discouraged, but instead work toward the country's goals is supported so vigorously that other activities seem to take a very minor back seat. Because of Singapore's exceptionally strong economy in recent years, there are large quantities of money available for the right kind of applied research. For example, the Government has recently announced that over the next 5 years it would spend about $S2B (about $1.3B) on the information technology part of a National Technology Plan and that by 1995 the research and development investment would reach 2% of the country's gross domestic product (GDP). The money will be focused in areas where Singapore feels it will do the most good, specifically manufacturing, computing (more generally, information technology), and biotechnology. Of these, manufacturing is seen as the key sector for the growth of Singapore and CIM is seen as the bridge between computing and manufacturing. The mission of the research community, at least with respect to manufacturing, is to invigorate the manufacturing sector with many aspects of IT. More specifically this means

- Provide training/consultancy/ education in use of IT in manufacturing.

- Provide value-added solutions building on top of existing tools (system integration/customization).

- Develop generic manufacturing applications such as manufacturing simulator, document management system, neuro-fuzzy controller, etc.

- Provide general assistance in national efforts in IT.

A very hard-headed look has been made into what this takes. For example, a chart was produced plotting technologies on the x-y axis of competitive (Singaporean) advantage versus benefits. Those technologies in the upper right-hand corner, knowledge systems, CIM, local/wide area networks (LAN/ WAN), Asian language, video text, and EDI value-added networks, are those that will get the most attention and support. Interestingly, technologies in the lower left corner are parallel processing, neural computing, fuzzy systems, and B-ISDN. (This view is not very different from that proposed for the EC.)

In software more generally, the country sees that open systems, software development methodologies, object-oriented (OO) techniques, and CASE are most critical to its software industry. In a related study, Singapore feels that between 1995-2000 the key technologies that will be absorbed into manufacturing will be virtual reality, machine vision, EDI services, E-mail, high performance computing, and advanced control. Areas such as fuzzy logic, simulation, real-time systems, and electronic document management are already viewed as having been absorbed, and new technologies that are currently being absorbed include neuro-fuzzy control, image processing, and distributed processing.

The trends that are seen in detailed manufacturing, at least in Singapore, are

- Trend toward mass customization (i.e., everybody's product is a custom job).

- Trend toward concurrent engineering (consideration of all aspects of product life cycle, from conception to disposal); also called simultaneous engineering.

- Trend toward flexible manufacturing (one assembly line easily changed; thus process rather than product specific).

- Trend toward information-based organizations (fewer levels of mid-management whose only job is to repackage and move information from bottom to top).

- Trend toward knowledge workers and integration of information.

In Singapore, industries are represented as shown in Table 1.

Manufacturing, mostly discrete manufacturing, is a major part of Singapore's success. In 1989 it produced more than one-quarter of the GDP (\$S63B), employed almost 400,000 people (more than one-quarter of the available manpower), and accounted for fully 65% of domestic exports. There were 3,700 firms employing more than 10 people, 580 firms employing more than 100 persons, and 125 firms employing more than 500 persons. Only the financial and business services sector contributes more to Singapore's GDP (40%).

Singapore has many things going for it.

Table 1. Singapore Industries

Industry	Establishments (%)	Output (%)	Value-Added (%)	Employment (%)
Industrial Chemical/Gasses	2.0	4.6	5.3	1.4
Paints, Pharmaceuticals	2.4	2.6	5.1	1.4
Electrical Appliances	3.5	3.3	4.0	6.2
Transportation Equipment	6.1	5.2	7.6	7.1
Electronic Products	6.5	39.0	36.1	35.6
Food	7.1	3.1	2.6	3.0
Printing/Publishing	8.7	2.4	4.1	4.4
Wearing Apparel	10.0			8.0
Machinery	10.7	4.5	5.5	6.9
Fabricated Metal Products	12.7	5.1	5.8	8.0
Petroleum Products		16.1	7.5	
Other Products	30.1	14.1	16.4	18.1

- A pool of educated and computer literate workers.

- Very generous government incentives for industry.

- World class manufacturing technology, mostly from multinationals. Some of this is potentially available for technology transfer.

- A strong research and development (R&D) infrastructure.

- Good tertiary institutions.

- Excellent communications network, and a compact country.

- Existing investment in CAD/CAM and automated manufacturing including more than 3,400 CAD workstations in smaller companies, 200 autonomous guided vehicles (AGVs), etc.).

- A group of very knowledgeable and capable leaders at the top to do planning.

But the country also has some obvious weaknesses.

- A large gap between the multinationals and the small-to-medium sized indigenous industries (SMEs). SMEs are seen as lacking both concept as well as technique, particularly in areas of measurement and quality control.

- Lack of downstream manufacturing design, particularly product design, which is seen to be very weak. Singapore has widespread applications in automation production and assembly systems of machine vision, industrial robots, etc., but feels that it lacks knowledge in interfacing and related software technology.

- A small internal market (Singapore is less than 3 million).

- Lack of experienced technical people.

- A reluctance to share information among its local companies.

It is clear from the first three points that Singapore must look at almost everything they do from an "international" perspective. As the world becomes a more peaceful place and international cooperation, rather than competition, is increased, Singapore will be a main and strong player.

As discussed in my earlier report, IT is highly developed in Singapore. In manufacturing more than 60% of manufacturers use some kind of computerized technology, although most of it is in accounting, finance, payroll, word processing, and inventory control. Naturally, computer usage is less in SMEs. For example, nearly 100% of the larger companies use computers for payroll, but only about 50% of the SMEs.

In the view of Singaporean scientists, future factories (year 2000) will be composed of intelligent manufacturing cells and built on the concepts of JIT (just in time), CIM, and concurrent engineering. Intelligent cells will have one to four computer-controlled processing machines capable of processing several parts simultaneously, connected by an automated material handling system and controlled by a programmable cell controller. One research project is to develop a truly adaptive manufacturing cell. It is expected to involve object-oriented modeling, expert systems, neural nets, and a simulation user interface for the operator. Neural nets will be used for pattern recognition, sensation, reaction, and control. Expert systems will provide machines with reasoning and deduction capabilities. The expert system controller will interact with modeling tools and engineering databases for process plans and will control machines via neural net schemes. With the help of simulators, an operator can predict what will happen and study what-if situations. On top of the factory system is a collection of software, distributed manufacturing resource planning, document management system, intelligent control, and intelligent interface software. This, in turn, is built upon various standards (such as X.400, IGES, Open Systems, etc.) and basic technologies (CAD/CAM, real time systems, etc.). In fact, standardization is an important component of Singapore's R&D programs in manufacturing.

Proposed areas for R&D in manufacturing are

- System integration tools and methodology to support CIM implementation.

- Shop floor control and monitoring systems.

- Development of knowledge-based systems for planning, scheduling, and fault diagnosis.

- Automated material handling.

- Automated warehousing and storage/retrieval system.

- Interorganizational information flow integration.

- System simulation for production planning.

- Flexible manufacturing systems.

- Document management systems and integrating information flow.

- Engineering databases.

- Expert systems for process planning and analyzing manufacturing systems.

This list is not far from Japan's IMS list of topics.

Several specific projects that I was told about include the following.

- GEMS (Generic Manufacturing Specifications) using CASE tools, designed for electronics and fabricated metal products industries.

- WINS (Worldwide INformation Services), designed to provide information from a large number of databases on markets, industry statistics, exchange rates, technology monitoring, etc. Singapore has already done an excellent job of integrating many government forms and making them available across a wide user base as computerized data. These include TRADENET for the export industry, GRAPHNET for exchange of CAD/CAM data, and BUILDNET for construction agencies.

- IMPACT (Intelligent Manufacturing Practices and ACTivities), which combines the ideas of sales/purchase orders over networks, engineering graphics interchange, expert sourcing of technology and product knowledge, and implementation of parts of CALS (the U.S. Department of Defense (DOD) computer-aided acquisition and logistic support). The view here is to do a better job linking information between companies.

- CLASS (Continual Learning and ASSessment), for training and upgrading skills.

Two specific projects are worth describing in detail. One is being managed by

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This project involves the development of a customizable knowledge-based simulator to aid planning and control. Nara is very realistic in assessing the use of simulation as one that

> May not offer the best solution, but brings out better solutions since these are the results of a series of repeated trials. Simulation experiments may be performed under every conceivable (sic) set of system conditions, parameters, or operating characteristics, and is more realistic as probabilistic models are used. With advances in computer graphics and modeling, one can have a good perspective of the system and see its behavior. Therefore, it helps in proposing a new system of improving the existing system.

The system consists of a scheduler, simulator, and knowledge-based analyzer. Production planning and control are treated as a management of flow of parts and information (process plans) through processors to produce end products. The scheduler module has some analytical methods like branch and bound as well as heuristic rules for the initial schedule. There is also the provision for bypassing this module and allowing the user to input his schedule or link the simulator to an MRP (manufacturing resource planning system). Event-oriented simulation modeling is used. The simulator keeps track of the discrete events occurring in the system and updates entities like work center parts and products at the completion of each event. Rules and knowledge of production planners will be stored in the knowledge-based analyzer module.

I met with Nara and listened to him explain the main ideas of his simulator. This is a nice project, but it is just getting started. I also met with one of the team members, a recent B.S. graduate who had very little experience in this area and was learning while programming in C++. Nara has many years of actual shop floor production experience.

The second project is by

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CIMIDES is a computer-integrated manufacturing information and data exchange system, which is in reality a network of mini expert systems and a director of information. The director coordinates the data exchange between the individual systems, both the raw data as well as deduced information, maintains consistency, and schedules and prioritizes contributions by use of a queue. Each mini expert system controls a specific area and has its own particular rules. These systems include the following.

- Intelligent Product Configuration System
- Knowledge-Based Product Designer
- Intelligent Component Designer
- Intelligent Knowledge-Based Object-Oriented Process Planner

- Modular Fixture Design Expert System
- Intelligent Quality Assurance Planner
- Intelligent Material and Equipment Planner
- Autonomous Guided Vehicle Planner
- Expert Production Scheduling System
- Flexible Manufacturing System Controller

Each mini expert system is developed using an object-oriented representation and the corresponding knowledge bases are organized into a ring structure. The main difference between this approach and other CIM systems is that it employs a common knowledge base rather than a common database.

GINTIC INSTITUTE OF CIM

From my perspective, the most interesting aspect of ICCIM'91 was the opportunity to see firsthand the work being done at GINTIC. This facility is located on the campus of Nanyang Technological Institute (NTI) about a 40-minute bus ride from the center of Singapore City, and essentially at the far west side of the island. Although NTI has been in existence since 1972, on 1 August 1991 it changed its name from an institute to a university (NTU); literature refers to both although they are the same place. Nanyang is the "other" large tertiary institution in Singapore, Singapore's National University being the first. NTU caters to about 9,000 mostly residential undergraduate students and about 400 graduate students, although some of those are part-timers. Its focus is on science, engineering, business, and management. It has the usual programs and some unusual ones such as graduate programs in International Construction Management and Hotel Administration. Special laboratories and centers include the Institute for Manufacturing Technology, Center for Advanced Construction Studies, Microelectronics Center, Computer Graphics Center, and Center for Transportation Studies. NTU emphasizes work-study programs; in the United States they are called co-ops, but Singapore calls them "business attachments." There are also a number of collaborative programs with Western universities, including the Sloan School at the Massachusetts Institute of Technology (MIT), the University of Warwick, and Loughborough University of Technology. The NTU campus, which rises somewhat Phoenix-like out of the tropical vegetation, is a study in modern cast concrete. The buildings, including many dormitories, appear to be no more than a few years old, although doubtless some are from the 1970s.

In my earlier report I described GINTIC briefly, but had no opportunity to visit at that time. This was originally established by NTI in partnership with Grumman in 1985 under the name "The Grumman International/NTI CAD/CAM Center" as a 5-year program to develop local CAD/CAM expertise. When the collaborative arrangement with Grumman ended in 1989, the organization was renamed GINTIC Institute of CIM; its 5-year period 1989-1994 is thought to be the second phase of its growth and is funded by the National Science and Technology Board at S$50.3M. The GINTIC mission is to develop local expertise in CIM applications by working with local partners on collaborative research, technology transfer, and training and education. GINTIC's role is perfectly consistent with the comments that I made earlier about manufacturing science research in Singapore.

It should be noted that the current GINTIC efforts are mainly focused on the software aspects of CIM. In fact, they have decided to establish a sister institute to GINTIC, called the Institute for Manufacturing Technology (IMT), with its own separate building next to GINTIC, that will focus on the hardware developments for CIM.

Currently, GINTIC is housed in several buildings near the Mechanical Engineering Department on the NTU campus, but a new building is to be built this year to bring the groups together and give them additional space. Currently there is a staff of 84 divided into four groups,

- Research
- Applications to provide services to industry
- Business to promote GINTIC and seek out commercialization opportunities
- Systems to provide support for the other groups

There is a management board and an international advisory panel, the latter including senior university scientists from Germany, the United States, Japan, and the United Kingdom. Research programs at GINTIC reflect the comments and views that have been made earlier.

- Management aspects of CIM
- System design
- System modeling and simulation
- Factory automation
- Product design

The emphasis on industrial technology transfer is apparent. For example, last year a CAD/CAM project for the jewellers industry was begun, as was a knee joint prosthesis project for Singapore Aerospace and the National

University Hospital. (We were told that Western research in this area was not sufficient for Asian people, who require greater flexibility for squatting. Interestingly, the joint model we saw has been developed in stainless steel and is very heavy. I would expect that new-materials research could provide alternative solutions.) Two new industrial services have been initiated--printed circuit board (PCB) design assembly and testing and rapid prototyping using stereolithography. The latter especially was a big hit when demonstrated at the ICCIM'91 vendor exhibit and later when it was shown to us at GINTIC. Stereolithography (SLA) was developed by the U.S. firm 3-D Systems and uses a laser on a liquid photocurable polymer to form models directly and very quickly from CAD/CAM data, so called direct three-dimensional (3-D) manufacturing. It is said to be a breakthrough because of the speeds with which prototype parts can be produced. SLA models are also heavily used for mold making, but most of the parts built this way are still only good for rapid prototyping, not real production (due to insufficient strength). GINTIC has 3-D Systems' 10-inch unit, allowing direct forming of parts up to 10 inches on a side (the company's largest unit allows 25-inch parts). Larger parts can be built in sections. (Several other U.S. and Japanese groups are also very active in this direct 3-D manufacturing technology.)

Education and training are accomplished by an emerging M.S. program in CIM just begun July 1990. Presently the program has about 40 students. There are also 2 Ph.D. students, 20 full-time (M.S.) graduate students, and 68 part-time graduate students. It should be mentioned that this program was heavily modeled after ones at RPI and Fraunhofer and that Prof. Lester Gerhardt (RPI), has been active in collaborating with GINTIC staff in forming the new program. In fact, Gerhardt is also a lecturer in their M.S. program.

The list below suggests the range of projects that are being studied.

At the CAD and Knowledge-Based Center

- Parametric feature-based intelligent component designer and modular feature design expert system.
- Intelligent knowledge-based OO process planning system for the manufacture of progressive dies.
- Daily production scheduling system for the manufacture of PCBs.
- Multilevel neural network job shop scheduling system.

At the PCB Flexible Manufacturing System (FMS) and SLA System

- DIP, axial, and radial inserters for through-hole boards.
- Screen printing.
- System for auto generation of insertion data for PCB assembly line.
- SLA for rapid prototyping.

At the Precision Machining FMS

- Hierarchical cell, workstation, and environment controller.
- ASRS workstation controller.
- Robotics modular fixturing workstation controller.
- AGV workstation controller.
- Vertical machining center workstation controller.
- CMM workstation controller.

A number of the research projects were presented at ICCIM'91 and these papers are included in the Proceedings. A good one (Lim, GINTIC) describes the control and communication system designed and implemented at GINTIC beginning in 1985. There is also a discussion of a C++ graphical toolkit (C. Wah et al.) developed using object-oriented techniques. At least one paper generated some healthy criticism. L. Tshon described a hierarchical approach to mechanical design based upon a tree of tasks, group leaders, and specialists. His approach allowed communication between specialists within a group but only between leaders of different groups, and even then only those at the same level. Along with several other members of the audience, I doubted that this very rigid approach would be successful at modeling real-world systems.

We mentioned earlier the AGV demonstration. This is very traditional technology but impressive that it was done locally by students. I shared the sense of many others that while researchers in the West should not look to GINTIC for really new ideas, they should be aware that new concepts will be tested here and improvements made, and if deemed useful, will be developed into working products for local industry. At the same time a large collection of specialists will be educated in their use.

JAPAN-SINGAPORE AI (JSAI) CENTER

This facility is housed on one large floor (1,200 m^2) of a building within Singapore's Science Park. It had its official opening during the week ICCIM'91 was in progress, and I took some time off from the meetings to visit. The program is viewed as an important step by both the Japanese and Singaporean Governments; the Japanese Ambassador to Singapore as

well as the Singaporean Minister for Finance presented speeches at the opening. A short history of the plans and construction of the facility was given via a slide show, and while lighthearted the message was clear; pictures of the new center were accompanied by the Hallelujah Chorus from Handel's Messiah and the theme music from "2001"!

Singapore is staking a significant fraction of its future on automation; the theme is that by the year 2000 Singapore will be an "intelligent island." To this end the JSAI Center is seen as a way of increasing awareness about AI in Singapore, learning needed skills, developing a friendly base between the two countries in a important technological field, learning about Japanese management practices, as well as building relationships and contacts. My earlier report detailed a number of AI-like projects that have already been implemented. In total about 50-60 projects have been developed; one-third are already in use, and the remainder are in prototype form. There are about 200 AI professionals now working in the country, while about three times that number are projected to be needed. The AI Center will be an important vehicle for accomplishing this goal. Japan has given the center about ¥380M (about $2.5M), mostly in the form of equipment (32 workstations, 25 386-PCs, 17 Macintoshes, etc.) and software. In addition to equipment, Japan provides software and technical expertise, while Singapore provides facilities, local personnel, and operating expenses. Six Japanese AI experts will work at the center and five or six Singaporeans will go to Japan for training with various companies (four are already there). It is also planned that about 500 training slots will be utilized within 4 years. In fact, training is a key element in the center. Three courses are planned. a 3-day course, "Intelligent Systems for Managers"; a 2-week course, "Intelligent Systems for Business Professionals"; and a 14-day course emphasizing more detail, "Expert Systems/Knowledge-Based Systems for IT Professionals." In addition, the heart of the program is a 6-month "Prototyping Expert Systems/ Knowledge-Based Systems" course, enabling trainees the opportunity to build prototypes of "real" systems under expert guidance. The Singaporean Government is encouraging industry participation in a very direct way, by providing a 70% absentee payroll subsidy for company-sponsored employees who are either Singaporean or permanent residents.

This is a "win-win" program as I see it for both Singapore and Japan. Others should view it this way, too, as long as they appreciate that the emphasis at the center is on real-world applications--this is definitely not going to be an academic research facility. Singapore gets specific assistance as outlined above. Japanese companies get to place their equipment, software, and personnel in Singapore and encourage use of their products during training, plus perhaps get assistance in developing marketable software.

After the formal opening, there was an opportunity to browse around the center and discuss various demonstration projects. These included a Tokyo subway advisor, production line diagnosis system, myopathy consultation system, hospital operation theater prioritization system, traffic data management system, production engineering expert system, pattern optimization system, etc. Many of them were running on NEC EWS4800 systems. A few are potentially useful, but others were obviously for teaching. In the latter category was the Tokyo subway advisor. A map of the (admittedly complicated) Tokyo system is displayed and then users select an origin and destination station (in Japanese). The system grinds (for quite a long time) while various rules are checked for the best route based on shortest time and/ or cheapest fare. I felt that most people could make a similar mental calculation in less time. Some constraints are allowed, however, and these could make such a system really useful, say at an airport. Unfortunately, the question asked by all Tokyo tourists--how do I get from here to there without going up stairs--was not available. Maybe later.

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The Japan-Singapore AI Center is not the only software R&D activity supported by non-Singaporean companies as Table 2 shows. The list of applications should be thought of only as representative. In addition, IBM, DEC, Sun, and probably other vendors have some software development in Singapore. Also in Singapore there is a French-Singapore (F-S) Institute and a German-Singapore (G-S) Institute on adjoining sites. Although I did not visit either place, at least one paper on FMS at ICCIM'91 was authored by a scientist from the F-S Institute (Fertin). Prof. Peter Sackett, Cranfield Institute of Technology (E-mail: sackett@ cim.cranfield.ac.uk), explained to me that the G-S Institute is more closely aligned to manufacturing than the French, which concentrates on IT issues, although both illustrate the Singapore approach by providing training, 40-week year, 2,000-h/yr classes in 2- or 3-year programs leading to a diploma (not a degree). Some institutions recognize outstanding performance on these programs as equivalent to a good degree

and valid as entry to a masters program. Sackett emphasizes that the institutes are not research oriented, although they are very well equipped and staffed, and they do undertake ambitious project work. One example is the building, again by students, of a fully operational FMS.

NATIONAL UNIVERSITY OF SINGAPORE (NUS)

While I had visited NUS earlier, I was anxious to visit again in order to see

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Nanda's work on user interface for numerical software was called to my attention by Prof. B. Datta. Prof. Nanda has his Ph.D. from New York University (NYU) (Courant) in functional analysis has been retraining himself in applied and computational areas. For several years he has been developing a system, running on a PC and written in APL, for plotting and manipulation of mathematical entities. His system has a number of special functions of mathematical physics built in, and he is working on other capabilities such as numerical integration, solution of differential equations, etc. Nanda claims that his targets are students, but in this arena there are already a number of good products, such as Matlab, MathCad, Mathematica, etc., and so he will have a tough time against those, especially as his system is not particularly extensible. Nevertheless, it is a good piece of work and he would like to hear from potential collaborators and users. At the moment he is developing this pretty much in a vacuum and definitely needs input and suggestions from outsiders.

During my visit Nanda showed me the computational facilities of his department, which are extensive, including numerous workstations, a very excellent computerized library card catalog, and a campus area network. But he was only mildly upbeat about the research activities. He felt that NUS students work diligently, but there are very few graduate students and that it will take time for the university to develop into a true research institution. In short, whatever money can buy has mostly been purchased; the rest is up to the faculty. NUS is encouraging visiting scholars and this will definitely aid the environment. I also had an opportunity to meet one U.S. visitor spending his sabbatical at NUS, Prof. Jerome Klotz, from the University of Wisconsin's Statistics' Department [E-mail: klotz@stat.wisc.edu]. Prof. Klotz echoed Nanda's assessment that NUS's students are hard working, but mostly not used to a Western style of student-professor interaction.

Table 2. Multinational Software R&D Centers in Singapore

Company	Year Opened	Application
NEC	1985	Office & factory automation, AI, product tools, etc.
Sony	1987	CAD/CAE (engineering), factory automation
Sing Eng/Ericsson	1987	Real time applications
Data General	1987	Unix, communication, Asian language, office automation
Nixdorf Computer	1987	Unix, communication, Asian language, expert systems
Hewlett-Packard	1988	Network products
Xerox	1989	Printing systems, document processing, Asian language
Ashton Tate	1989	Micro applications, Asian language, telecommunication
Omron Tateisei	1989	Software development center
Siemens	1989	Land use information systems
Fujitsu	1989	Telecommunication
Unisys	1989	Unix applications
Seiko	1990	AI, OO, fuzzy theory
Unibit	1990	Expert systems
Lotus	1990	Micro software

CONCLUDING REMARKS

Every visitor to Singapore is impressed with the physical facilities and equipment. I mentioned this above in the context of GINTIC and again about NUS. But people are worried about this hardware-heavy/but software-weak situation in their country. (Software here means particularly human resources.) Some Singaporeans feel that they are lacking a pool of experienced, well-trained people who can take full advantage of this wealth of hardware and hopefully lead their country to future growth. At the lower levels I have mentioned the emphasis on training already. At the higher levels this situation is claimed to be particularly bad at the universities, which are struggling to recruit good faculty members for their engineering programs. I was told that the Government has set up a special fund and laws to attract to Singapore those Chinese students who are graduating from good U.S. or European universities with doctoral degrees and who do not wish to return to mainland China. In addition to good financial incentives, they and their family members are granted immediate permanent residence in Singapore. Apparently some initial success of this special recruiting program has already been achieved.

All scientific visitors to Singapore must also come to grips with the realities of the political world here, which is not as open as one might find in some other countries. Singapore has been run in a very authoritarian way by its benevolent Prime Minister Lee for many years. The system is slowly changing, and to be fair most Singaporeans and many outsiders think that restrictions are reasonable and have benefitted their country. Nanda feels that it is still too soon to expect a completely open society, and perhaps this will never occur. Besides, the Western model is probably not appropriate in any country in Asia, and especially those with a Confucian streak that venerates age and family leadership. Singapore is free, but one doesn't step too far out of line here, anyway not if one expects to have a career and a future.

To repeat, coordination is a strong point in Singapore, strong leaders + good visions-->well planned actions-->careful monitoring of action results + revision of plans and visions. Sounds reasonable, and certainly appears to work in this small country.

ACKNOWLEDGMENT

I wish to note my sincere thanks to Profs. Lu (University of Illinois), Gerhardt (Rensselaer), Sackett (Cranfield), and Ho (GINTIC) for reading this report and for their many helpful comments and suggestions.

FIRST KOREA-JAPAN CONFERENCE ON COMPUTER VISION

The First Korea-Japan Conference on Computer Vision, held 10-11 October 1991 in Seoul, Korea, is summarized and assessed.

by David K. Kahaner

INTRODUCTION AND SUMMARY

The First Korea-Japan Conference on Computer Vision was held on 10-11 October 1991 in Seoul's KOEX Conference Center. Approximately 80 papers were presented (31 from Korea, 47 from Japan) in three parallel sessions during the 2 days. (KOEX, a massive convention facility, could easily have swallowed 50 such conferences.) Two invited papers summarized computer vision research in Korea and Japan, respectively, and a panel discussed "Application of Computer Vision for Automation." There were about 200 attendees. As few Japanese or Koreans know each other's language, the conference language was English. Korean scientists are very far behind in development and industrial applications of computer vision. In basic research they are lagging a bit less because many Korean scientists have done research work abroad in the United States and Japan and are attempting to continue that in Korea. Both countries see analysis of moving images as the most important new research area, although many "standard" topics are far from solved. (The recent interest in movement stems from increasing processing speed. Without fast computers and fast data movement, researchers had to sample images every second or two, leading to very complicated relations between successive frames.)

Conference chairmanship was shared between

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I had met Prof. Lee almost 20 years earlier when we were both in the Mathematics Department at Ann Arbor. He was trained as a pure mathematician but is now interested in applied problems, particularly those concerned with computer vision.

The fairest things that can be said about this conference are that (1) the Korean scientists were very brave to have organized it, especially to have scheduled more or less alternating talks describing Japanese and Korean research; and (2) the Japanese scientists were very gracious to have participated so enthusiastically. A preview of what was going to happen was given at the opening lectures when research in the two countries was reviewed. A literature search on computer vision uncovered fewer than one-tenth as many Korean as Japanese research papers.

Although the paper balance at the conference was much more even, it was very clear that Korean research is at a much earlier stage and that applications of vision in industry are much more limited than in Japan. There were a (very) few exceptions. For example, Prof. T. Poston in POSTECH's Mathematics Department [E-mail: tim@vision.postech.ac.kr] gave an elegant discussion of the use of singularity theory for vision applications, but at the moment this work is very far from practical realization. Also, some Korean industry is using vision techniques and, in particular, Samsung has a visual soldering inspection system that has many similarities to systems developed by Toshiba and NTT.

Computer vision is usually thought of as beginning with a real world situation (scene) that is input through a camera and then digitized and ending with a description of the scene, e.g., knowledge (perhaps leading to action which changes the scene, etc.). The in-between steps are often modularized. Typically there is a "camera model"

relating to color, range, separation of cameras for stereo images, and other parameters that is used at the input phase. Next, properties of the image are invoked to locate image features such as edges, lines, or regions. This phase is usually called feature extraction. Lastly, at the highest level, there is some underlying object model, for example, the designer knows that the scene is supposed to be of an automobile, and then matching is done to locate these objects in the scene. This involves solving problems such as direction, angle, and occlusion. The result is scene description or scene knowledge. Research in computer vision is often compartmentalized into subtopics that follow this modularization as well. For example, "image processing" usually refers mostly to the lowest levels, whereas pattern matching research almost always refers to the highest level.

In computer vision research it is not too difficult to get to the leading edge of what has been accomplished, and thus almost any project will quickly need to address advanced problems. But simply put, because the Japanese have tried so many different approaches, their breadth of research experience is very much greater than the Korean's. They are also trying deeper and more sophisticated techniques, although the disparity might not be too great in a few specific promising areas such as scene identification.

JAPAN AND KOREAN COMPUTER VISION SUMMARIZED

From the Japanese side

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presented a clear summary of past work in Japan. Shirai pointed out that Japan has a Computer Vision Group with about 500 Japanese members. They meet bimonthly and had their first symposium this summer (this is in additio' to any international meetings that have been held). The group's chair is Prof. Yachida, mentioned above. There is a Special Interest Group (SIG) in Pattern Recognition and Understanding (until recently Pattern Recognition and Learning) sponsored by the Institute of Electronics, Information, and Communication Engineers (IEICE), which publishes about 125 papers yearly in 10 issues. This group also includes a small amount of speech recognition. There is a Special Interest Group in Computer Vision (SIG CV) sponsored by the Information Processing Society of Japan (IPSJ), focusing on image processing, that publishes about 60 papers each year in a bimonthly journal. Finally, there is also a SIG in Pattern Measurement sponsored by the Society on Instrumentation and Control Engineers (SICE), which publishes about 20 papers yearly in four issues, but this is heavily oriented toward very practical hardware problems.

A survey of the database of information processing literature in Japan (this covers the period 1986-1988, the latest data that are available) characterizes computer vision related papers as follows (excluding coding of images).

Topic	No. of Papers
Applications	477
Drawings (96)	
Medical (85)	
Characters (81)	
Industrial (75)	
Scientific (64)	
Remote sensing (40)	
Intelligent robot (36)	
3D input and recognition	132
Feature extraction	105
Hardware systems	89
Image understanding	82
Stereo (or multidimensional)	62
Time sequence images	46
Image database	45

Shirai pointed out that in a few areas, such as industrial applications, there is far more work than is represented by the number of published papers.

The only more recent data are from the IPSJ's SIG CV for 1990-1991:

Topic	No. of Papers
Time sequence images	18
Feature extraction	12
3D input and modeling	10
Stereo	9
Medical	8
Matching	6
Neural network for matching	6
Shape from X	5
Face	4

It is clear that the most important new area is analysis of sequences of images, and this view was also shared by the Korean attendees. While there are only four papers concerning computer vision in the field of human faces, this is also seen to be a growing area, incorporating human computer interface, remote teleconferencing, human emotional information processing, and image coding.

Shirai went on to describe several specific Japanese projects that involve computer vision. The most elaborate of these is the ¥20B ($140M) 1983-1991 "Robot for Extreme Work" project, in which the ultimate application is the development of an autonomous teleoperated robot for nuclear plant, pipe cleaning, underwater, and emergency (such as fire) operation. This particular project involves much more than just computer vision, and in fact

research has been done on fundamental problems of locomotion, teleexistence, manipulation, and sensing, as well as the development of a system integration language. The part of the project dealing with these fundamental issues actually received the bulk of the funding, and more applied aspects, i.e., to really develop such a robot, were not so well funded. In addition to Japanese universities, the Electrotechnical Laboratory (ETL), Fujitsu, Toshiba, and other companies participated--Toshiba working on feature extraction and Fujitsu on projecting images onto a sphere (which Shirai claimed works well in clean environments). ETL has done a great deal of work on sensing, stereo, and robot vision language development and actually issued a special issue of the *ETL Bulletin on Robotics* in which this has been summarized. Shirai showed several photos of the prototypes that had been developed. One of these looked like a monster from "Star Wars II," and Shirai admitted that 8 years was a long time for this technology and that a newer project would have designed a less clumsy looking robot.

Another interesting Japanese project is a vision-based vehicle system. This shares some of the same goals as similar projects in the United States, such as at Carnegie Mellon University (CMU). The Japanese project [which is also supported by the Ministry of International Trade and Industry (MITI)] is in two phases. The initial or phase-0 part was mostly done by Fujitsu and Nissan around 1989 and involved a vehicle on a special test course, shadowless illumination, and only large obstacles. The vehicle (a motor home) has three cameras for lane detection and two more for obstacle avoidance and a sonar system. Techniques used are line following for lane finding and sonar for obstacles and for range finding. Phase-1, which runs from 1989 to 1995, involves learning how to run the vehicle on a highway with a centerline by distinguishing line and road boundaries and also road signs. Phase-2, from 1995 to 2000, will deal with multilane highways, tunnels, rain, windshield wipers, and using stereo for obstacle avoidance. Phase-3, from 2000 to 2030, will (hopefully) deal with normal roads, crossings, parking, backing up, and using a mirror and will involve tools of scene understanding and map matching. This project also has a very unique perspective on wanting to use active sensing, for example, to help the scene understanding by using sound and to understand the sounds being received by use of the input visual data. Thus the project designers are thinking about sensor fusion and multisensor integration. These parts of the program will begin soon at Tokyo University. Shirai admitted that at the moment image segmentation is one of their most difficult problems, but he did show us some film of the motor home on its test road and it seemed to be working, although rather slowly. This appeared to be at a much less advanced state than the CMU project I saw more than a year ago.

From the Korean side

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gave a summary of computer vision activities in Korea. Until very recently there was not much to report, and even today he emphasized that industrial applications are very limited. Most research is occurring at universities and government research institutes using facilities imported from other countries. Several Korean companies do market low-price machine vision systems developed in Korea but, to date, their performance has not been impressive. Production line utilization of computer vision is infrequent and limited to simple inspection and very repetitive tasks. Park claimed that Korean companies would rather not purchase a general purpose vision system such as a Sammi-AB but prefer to obtain very task-specific systems. Industry does see a very strong need for efficient algorithms for segmentation, classification and, of course, for high reliability.

Before 1989 work was very scattered and mostly restricted to workshops and courses in medical imaging, computer-aided design/manufacturing (CAD/CAM), image processing, and computer graphics. Modern work really begins only in 1989 with an Image Processing and Image Understanding Workshop (at POSTECH) at which time it was decided to have annual workshops in order to share research activities. Subsequently, two workshops have been held with a total of 42 papers presented. Two related meetings are worth mentioning, an International Workshop on Medical Imaging (March 1991 at the Korea Institute of Science and Technology) and a Chapter Meeting of the Korea Information Society (May 1991 at Chung-Joo University), which had as its theme "Current Status of Pattern Recognition Technology" and generated half a dozen overview papers. There are now three SIGs interested in vision: SIG AI (artificial intelligence) (Korea Information Science Society), SIG IP-TV (information processing) (Korean Institute of Telematics and Electronics), and SIG Images (Korean Institute of Communication Science).

Park also gave a list of research activities at various Korean research centers (see the Appendix) but did not

go into detail about the projects. This list gives a realistic sense of the work going on in Korea. Because the data were collected by asking scientists, the amount of thought and detail provided varies greatly (how many PCs does a Cray-2 equate to). But by scanning this, it is very clear that there are only a very few places with substantial equipment resources with respect to vision. I will try to obtain more details about the actual progress of the research at those institutes. Park did show AVIS (a project at POSTECH), which is an automated inspection system for use in the Pohang steelmaking factory using the PIPE computer (purchased from Aspex). It is also installed at the Korea Advanced Institute of Science and Technology (KAIST).

For the future Park felt that vision work should concentrate on factory automation, that biomedical applications were still a promising field that could have broader applications, and that handwritten character recognition was the key to office automation applications. In the area of more fundamental research, he felt that Korean scientists should work on moving target detection, remote sensing, mobile robots, and other motion-related problems and that the Korean Government needed to take a more active role with additional funding, manpower development, and mechanisms to encourage cooperation between industry and university, as well as international cooperation.

PANEL DISCUSSION: APPLICATION OF COMPUTER VISION FOR AUTOMATION

This was the most fascinating part of the meeting, as it placed six experts together and gave each an opportunity to describe work that they had seen and work that they were hoping would be done in the future. Panelists were

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Unfortunately, none of the panelists provided handouts and so my summary below is based on notes that may not be completely accurate.

Ejiri (Hitachi) only made a few remarks but pointed out that vision systems were realized in Japan 20 years ago. (See my comments earlier about depth and breath of research vis-a-vis Japan and Korea.) He also pointed out that there was very tough competition between Japanese companies but very friendly discussions between researchers. (Isn't this the Japanese way; maybe this is the reason that everybody's soldering inspection systems look alike.)

Kuno (Toshiba) claimed that more than 100 computer vision applications were developed at Toshiba. Not all were successful and most were developed for position detection. The ones that

work have a common thread that they begin with a good (high contrast) image input. He mentioned three specific examples of vision systems now in use within Toshiba but did not go into any real detail about any of the specific hardware or software techniques that were used.

- Soldering inspection system for the mounting of integrated circuits (ICs) onto printed circuit boards (PCBs). In some sense this is a very simple problem, as there is a clean model of what the image is supposed to look like. The hard part of this problem is to get good input images. Toshiba's inspection station uses 168 light-emitting diodes (LEDs) to illuminate different parts of the target.

- Agricultural automation. This involves using a robot to cut young plants at the proper stem length.

- Digital audio tape, and VCR, magnetic head gap-width adjusting system using computer processing of images of Moire patterns.

Kuno commented succinctly about the state of the art, that "we are using '70s algorithms on '80s hardware." As for the future he felt that there would be no general purpose vision system in the near future because of cost issues. In his view there are three basic ways to use computer vision systems.

- Use simple (e.g., low cost) vision system cleverly for factory automation, human computer interface, etc.

- Apply heuristic tuning to fields with strong needs, e.g., character scanning/recognition is a perfect example.

- Do basic research on sophisticated vision systems for future applications, such as robots, nuclear power plants, space work, etc.

Presumably Toshiba's research support will follow these paths.

Tajima (NEC) felt that for image processing (as opposed to image understanding) there were already very cheap general purpose systems with many operators built into hardware for preprocessing (such as thresholding, etc.). He then went on to give a rapid description of a collection of vision applications within NEC, again with few details.

- Multilayer substrate inspection station to detect short circuits, pin holes, etc. for use with the boards NEC uses on their supercomputers (SX series). This system can inspect a 225-mm^2 board area in 25 minutes.

- Soldering inspection station, looking a great deal like Toshiba's, with five cameras and lights for three-dimensional (3D) views.

- Deformation measurement by laser range finding for circuit boards.

- Inspection system for determining if foreign objects are inside empty (Coke) bottles, and another system for determining the amount of liquid in a bottle.

- A 3D human body measurement system. This was the most intriguing of the lot. The application here is to determine the tailoring of apparel by measuring cross sections of humans. The subject is in a box and is illuminated by six lasers. The software uses a body model that runs on a workstation and a database that runs on a minicomputer.

As far as industry was concerned, Tajima felt that the important work needs to be done in 3D recognition as well as motion detection, and that recognition of features needs to be above 99% to be industrially useful. He felt a standardized database of images would be very helpful for studying algorithms. As far as new directions, he mentioned the importance of sensor fusing to enhance the reliability of existing techniques.

Shakunaga (NTT) claimed that NTT was trying to combine visual information processing with other technologies to develop applications in the area of advanced visual telecom services and network support, both of obvious importance to NTT. He gave two examples.

- Maintenance. A manhole facility inspection system using a truck-mounted, underground-looking radar that eliminated the need for digging to locate pipes. This uses pattern recognition and frequency domain analysis. This is said to work to a depth of 1.5 meters, which includes 75% of the company's pipes. (If you have ever lived in "dig we must" New York you will know how welcome such a system would be.) A second system uses a TV camera on a stalk that looks inside manholes and generates a stereo view of the facility's layout inside (using vertical camera movement for the second image) and then generates a drawing of the manhole contents. This uses edge detection, which is said to be accurate to 0.05 pixel.

- Human computer interface. The idea is to transmit less feature data for teleconferencing. NTT has been experimenting with human head, lip, and body image readers. The idea is to interpret head motion and generate understanding based on head movement. This uses edge detection of head silhouette and analysis of facial area.

Shakunaga divided future research themes in three directions.

- Early vision. Because human systems are very adaptable, we should study adaptive tuning of input data and attention getting mechanisms. We should also study human implementation of early vision algorithms for edge, region, texture, shape, distance, motion, etc.

- Middle level vision. Requires research into model based matching, from specific (recognition) to generic (cognition).

- High level vision. Study 3D world description and manipulation. Consider integration of vision and semantic databases.

Kim (Samsung) felt their problems were similar to NTT's and to Toshiba's. He also felt that the cost of vision systems will be coming down quickly, although this is now still a bottleneck. He gave a short list of computer vision applications but with even fewer details than the other industrially based speakers.

- System for mounting a screw in a microwave oven cavity.

- Simple assembly.

- Soldering system for inspection and modification, again very similar to NEC's and Toshiba's.

- Color monitor.

- Mobile navigation.

The motivation for reducing the cost of inspection was made clear to the audience--Kim pointed out that at Samsung a very large fraction of the electronic manufacture employees are doing inspection and adjustment related jobs.

Choi (Chung-ang University) described work in 3D vision. Of course, the major problem is to extract information about a 3D world from two-dimensional (2D) images. This can begin with range finding, for knowing the distance to objects will then allow one to determine which one is in front, etc.; or it can begin with finding segments, features, objects ... to which stereo, etc. can be applied. (An occlusion boundary, for instance, allows triangulation on the occluding edge--it is not a feature of the occluded object.) The two approaches are:

Passive

- Monocular vision requires *a priori* information (in some problems this is available).

- Photometric stereo, e.g., using different light sources.

- Shape from shading, although recovering surface orientation from a single image is obviously ill posed as are many of the monocular techniques.

- Range data from two different images, or a sequence.

Active

- Structured lighting (mentioned work by Prof. Sato and also work at CMU).

- Time of flight (sonar, etc.).

- Conventional triangulation as with range finders.

None of the techniques is best for all situations and ultimately the system designer must choose the most appropriate. Systems with low cost and high performance are not available, certainly not in a factory situation. There are no camera standardizations. Missing scene parts and shadowing are a problem, as obviously it isn't possible to deduce 3D data for missing parts of a scene.

COMMENTS ABOUT SPECIFIC CONTRIBUTED PAPERS

A complete list of titles/authors of the presented papers is being prepared and will be distributed (electronically) as soon as it is ready. However, topics discussed included

- Character recognition & document understanding
- Image processing & coding
- Hough transform
- Scene understanding & object recognition
- Neural nets
- Stereo & shape recognition
- Motion & sequential image processing
- Sensing & recognition
- Mobile robots
- Vision paradigm
- Computer vision hardware & algorithms
- Motion & shape reconstruction
- Intermediate & high level vision
- Thinning, quadtree, & component labeling
- 3D modeling & recognition

- Feature extraction & object recognition
- Applications

I would like to express my sincere thanks to

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who contributed the following material. Readers should note that many important Japanese research topics on computer vision were not presented here.

It has been said that if all a rat knew of rat psychology was the information in psychology textbooks, he would fail every social interaction he attempted with another rat. Similarly, if the processing of his visual input rested on current algorithms for vision, he would be safest to rely on his excellent sense of smell. Broadly speaking, most computer vision applications depend on an extremely predictable environment: "is that a nut or a bolt?" algorithms that depend on consistent lighting and would often report "bolt" for a severed finger. The highly stereotyped behavior of an animal adapted to cage life (and no longer viable in the wild) is richness itself compared to any manufactured system. Since back-of-the-envelope calculations suggest that the processing capacity of the current generation of supercomputers is up there with the nervous system of a housefly, it is a remarkable fact that progress is, in fact, being made in solving visual tasks far more interesting to humans than anything a fly can do.

This meeting was reasonably representative of the state of the art. For example, one Korean paper (Ref 1) at this meeting reported on a system for extracting car types and license plate numbers from camera images, that is, in place and working well in its limited universe of car and plate types. The problem of workaday character recognition is a much larger one in East Asia than in pure-alphabet countries (though even there decorative scripts, from Shatter to ornamental Arabic, make a universe too wild and varied for existing computer methods). A Japanese high school graduate is supposed to recognize about 2,000 Chinese characters; a Korean who knows only the phonetic script is functional but cannot read (for instance) most newspaper headlines. Identifying characters from a universe of thousands, even in a fixed typeface, is a qualitatively different problem from working with Western character sets. Just as with English writing, handwritten text has far more variation and consequent difficulty. Thus to achieve over 98% cumulative accuracy on a realistically large character set is not a small achievement. This was done by two Japanese papers in radically different ways. One (Ref 2) used Fourier transforms of rectangular windows within a character to estimate how like a diagonal/vertical/etc. stroke that part of the character seemed, tested on 881 character categories from a standard database of handwritten characters. The other (Ref 3) worked on the cheap printing in a translated Isaac Asimov novel (processing it in about the time Asimov seems to need to write one), which involved 1,164 distinct characters. This paper used a more directly geometrical approach, searching for pieces of approximate straight line within the image, calculating their lengths, and so on. Many other methods are under development (some of which look unlikely ever to scale to a large character set with good reliability); this contention of innumerable ideas reflects the direct importance of the problem, its attraction to vision researchers as a problem universe of large but controlled size, and the lack of conceptual convergence in this area. There are so many uses for automated literacy that effort and resources will continue to pour in this direction, but it would be unwise at this time to place any bets on what method--existing or still to be developed--will finally dominate the field of character recognition.

In any meeting about computer analyses and decision-making, nowadays, one expects neural networks. At this conference there were five: using networks for identifying objects in an image ("Choose one out of Sky/Grass/Road/Tree/Road/Car") (Ref 4), segmenting simple images ("Separate this stool sketch from the background sketch of floor and folding screen") (Ref 5), stereo matching (Ref 6), an image thinning method (Ref 7), and a classifier for polyhedra with up to eight faces, at most four meeting at a point (Ref 8). As is common for neural net research, the problems handled were quite small, and while directions for development were pointed out, there was no analysis of the way the network's necessary size and learning time would scale with the complexity of the problem. In most network problems, unfortunately, these scaling properties are abominably bad, so that the network "solution" is no better than a classical algorithm that takes exponential time or worse, except for the "learning" that reduces the load on human intelligence in creating the solution. Some of the papers here may scale usefully--some neural networks are proving useful in practical applications--but none of them address the question.

The enormous range of methods applied to scene analysis (optical flow, modelling of the object seen and comparison of the image with prediction, fitting a distorted quadric surface,

analysis of a moving 3D outline, shape from shading...) generously represented at this meeting represents not only the immaturity of the field (as with character recognition) but almost certainly the multifaceted nature of the problem. The human vision system can respond "couple dancing!" to a grey-toned image, a line sketch, a half-second movie showing only points of light attached to dancers in the dark ... and thus solves its problems in multiple ways. This multiplicity is presumably in some sense necessary, as the evolutionary cost of evolving it cannot have been low. Complicated systems have many potential defects, so that many mutations could cripple them, and very few--at a given moment--improve their present working. The papers here represent normal progress in existing approaches to subproblems in the Great Problem of "What am I seeing?"--a number of papers that specialists will need to read, but nothing that starts a whole new approach, or represents a step toward the problem created by the multiplicity itself. Given that a robot fit to explore a rich environment will almost certainly need (like the mammalian brain) to use many submethods in visual analysis, how should it integrate the results? How should the computer/how does the brain represent the objects about which so much information arrives in conflicting formats? As each submethod becomes more powerful, the problem of integration or "sensor fusion" becomes more urgent. Since major progress here would be a large step toward understanding the dynamics of consciousness, it is not a trivial problem. Not surprisingly, at this meeting there was no session on integrating the output of the descriptors for rigid shapes, faces, etc. discussed in the many papers on how to use camera images, range data, and so forth.

As one might expect, given the respective research populations and funding of Japan and South Korea, there were 47 papers from Japan against 33 from the host country, of which a certain number were "trial flights" by graduate students giving their first conference papers. In some cases, this was painfully obvious in the quality of the work as well as in the confidence of the presentation. The experience of placing work in the setting of a larger and more developed research effort will certainly be strengthening for Korean work in computer vision.

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2. "Recognition of Handprinted Characters by FFT," Tadayoshi Shioyama and Akira Okumura, Kyoto Institute of Technology, Japan.

3. "An Experiment on Printed Japanese Character Recognition using a PC for the Braille Translation of Novel Books," Yasuhiro Shimada and Mitsuru Shiono, Okayama University of Science, Japan.

4. "Hopfield Net-Based Image Labelling with MRF-Based Energy Function," Byoong K. Ko and Hyun S. Yang, KAIST.

5. "Image Segmentation Using Neural Networks," Ao Guo-Li, Cui Yu-Jun, Masao Izumi, and Kunio Fukunaga, College of Engineering, University of Osaka Prefecture, Japan.

6. "Stereo Matching Using Neural Network of an Optimized Energy Function," Jun Jae Lee, Seok Je Cho, and Yeong Ho Ha, Kyungbuk National University, Korea.

7. "Automatic Construction of Image Transformation Processes Using Feature Selection Network," Tomoharu Nagao, Takeshi Agui, and Hiroshi Nagahashi, Tokyo Institute of Technology, Japan.

8. "3-D Polyhedral Object Recognition using Fast Algorithm of Three-Dimensional Hough Transform and Partially Connected Recurrent Neural Network," Woo Hyung Lee, Sung Suk Kim, Kyung Sup Park, and Soo Dong Lee, Ulsan University, Korea.

Appendix

RESEARCH ACTIVITIES AT KOREAN UNIVERSITIES/ RESEARCH INSTITUTES IN COMPUTER VISION

[Data collected by Prof. Joon H. Han, POSTECH, and Prof. Hyun S. Yang, KAIST]

KYUNGBUK NATIONAL UNIVERSITY

A. Research Areas

1. Computer Vision (stereo vision, pattern recognition, range image analysis, motion estimation)
2. Image Analysis (restoration, enhancement, edge extraction and thinning, segmentation, data compression)
3. Neural Network (pattern recognition, stereo vision, image analysis)

B. Projects (partial list)

1. 3D object recognition from 2D images
2. Development of shape recognition and synthesis technology by using image processing techniques
3. Integrated circuit (IC) layout pattern recognition by using image processing techniques
4. 3D shape and motion recognition
5. Studies on human vision

C. Facilities (image processing lab)

1. Color image processing system (IBM PC/AT with color image processor, color CCD camera (512 x 512 x 8 bits), color monitor)

2. Pseudo color/BW image processing system (IBM PC/386 with ITI ljl series image processor, IBM PC/AT with ITEX-PC-Plus, color CCD camera (512 x 512 x 8 bits), B/W monitor)

3. Stereo vision system (IBM PC/AT with FG-100-AT frame grabber, two CCD cameras, B/W monitor)

4. Laser range scanner system (Technical Arts) (100X scanner, solid state camera (ICIDTEC), RCA monitor, laser power supply, Visual 500 terminal)

5. SUN 4/260C workstation (color graphic system, color monitor (1280 x 1024), digitizer tablet, plotter)

6. IR Camera
7. Film Recoder
8. Printer

D. Faculty - Prof. Sung Il Chien

SOGANG UNIVERSITY

A. Research Areas

1. Character Recognition
2. Stereo Vision
3. Image Coding

B. Faculty Members - Prof. Kyung Whan Oh, Prof. Rae Hong Park

SEOUL NATIONAL UNIVERSITY

Signal Processing Lab

A. Research Areas

1. Image Coding [2nd generation coding, region based coding, texture analysis/synthesis, motion compensated coding, motion detector, target tracker (real-time)]

2. Computer Vision (low-level segmentation (color, B/W), shape matching (relaxation), polygonal approximation)

B. Facilities (Gould 8400 IP + 19-inch RGB monitor, Micro-VAX II, Image Technology IP512 Image Processing System, SNU RGB Image Processing System, PDP 11/23, IBM PC 386, AT, XT)

C. Faculty - Prof. Sang Uk Lee

Automation & Systems Research Institute

A. Research Areas [Computer Vision (low and high level)]

B. Current Projects (On the development of a color vision system employing DSP, Real-time vision system)

C. Facilities (SUN 4 workstations, CCD camera, Adaptive robot, IP 150 Image Processing System, IBM PC/AT, 386 etc.)

D. Researchers - Prof. Sang Uk Lee (SNU), Prof. Jhong Soo Choi (Chung-Ang Univ.), Prof. Rae Hon Park (Sogang Univ.), 6 research assist.

YONSEI UNIVERSITY

A. Research Areas

1. Neural Network Modeling
2. Korean Character Recognition
3. Dynamic Character Recognition
4. Korean Character Processing Computer

B. Facilities (Micro-VAX II, Vax II/750, Solbourne, IBM PC/AT, scanner, B/W camera, printers)
C. Researchers - Prof. Il Byung Lee, ~10 graduate students

CHUNG-ANG UNIVERSITY

Image & Information Engineering Lab

A. Research Areas

1. Medical Ultrasound Imaging
2. Computer Vision
3. Visual Communication

B. Current Projects (a study on image understanding system using active focusing and meta-knowledge)
C. Facilities (workstations, PCs 132-bit, image data acquisition system, plotter, logic analyzer, IBM 3090)
D. Researchers - Prof. Jong-Soo Choi, 1 assist. prof., 17 graduate students

Computer Vision & Graphics Lab

A. Research Areas

1. Computer Vision
2. Image Understanding
3. Pattern Recognition
4. Computer Graphics

B. Projects (partial list)

1. Construction of image understanding system
2. Basic research on image processing
3. Basic research on artificial intelligence

C. Facilities (CCD camera, frame grabber, PCs)
D. Faculty - Prof. Young Bin Kwon

CHOONGBUK UNIVERSITY (AI LAB)

A. Research Areas (Projects)

1. Development of On-Line Handwritten Chinese Character Recognition
2. Evaluation of Image Skeleton Algorithms

B. Facilities (SUN SPARC workstations, Macintosh workstations, VGA color PC 386, VGA color Notebook 386, WACOM SD-510C tablet digitizer, laser beam printers, IBM PC/ATs)

C. Researchers - Prof. Seong Whan Lee, 5 graduate students, 2 research scientists

KOREA ADVANCED INSTITUTE OF SCIENCE & TECHNOLOGY (KAIST)

Visual Information Processing Lab, Center for Artificial Intelligence Research

A. Research Areas

1. Sensor-Based Intelligent Mobile Robot
2. Knowledge-Based Computer Vision
3. CAD-Based Computer Vision
4. Neural Network-Based Computer Vision
5. Character Recognition and Document Understanding
6. Computer Graphics

B. Current Projects

1. Development of intelligent mobile robot
2. Knowledge-based image understanding system for 3D scene interpretation
3. CAD-based 3D object representation and recognition

C. Facilities (PIPE 1/300 Image Processing Super Computer, Mobile robot, SUN workstations, IBM PC 386, CCD video cameras, 400-dpi image scanner, X-terminals, VGA monitors, 21-inch high resolution color monitor)

D. Researchers - Prof. Hiyun S. Yang, 2 KAIST faculty, 7 other university faculty, 12 graduate students

Image & Communication Lab

A. Research Areas

1. Image Coding and Transmission
2. Color Image Processing
3. Image Understanding and Applications
4. Dynamic Scene Analysis
5. Channel Coding and Wideband Systems
6. Character Recognition
7. Hierarchical Coding
8. 3D Image Processing
9. Texture Image Processing
10. Shape Recognition Algorithms

B. Facilities (Micro-VAX 11, SUN workstation, Gould IP8400 and Real-time video disk, KAIST vision system, color camera for TV broadcasting)

C. Researchers - Prof. Jae Kyoon Kim, Prof. Seong Dae Kim, ~30 graduate students

POHANG INSTITUTE OF SCIENCE & TECHNOLOGY (POSTECH) (COMPUTER VISION GROUP)

A. Research Areas

1. Image Processing Algorithm Developments for Parallel Processing Computer (POPA)
2. Pattern Classification Using Computer Vision
3. 3D Object Modeling

4. Stereo Vision
5. Korean Character Recognition Using Neural Networks
6. Image Understanding
7. Robot Vision
8. Medical Imaging

B. Projects (partial list)

1. On-line detection of surface faults on metal plates
2. Autonomous land vehicle navigation
3. Development of slab number recognition system by using an image processor
4. Development of range image sensor
5. Development of high-performance parallel computer for image processing
6. Wavelet transforms for image processing and image understanding
7. Development of robot vision system for automatic assembly of automobile parts

C. Facilities [POPA (Pohang Parallel Architecture, transputer-based); PIPE model 1 system (image processing and understanding system); Gould IP 9516 image processor (micro-VAX host); ITI 151 image processing system; Solbourne 5/602; Sun workstations; Neuralworks; ANZAplus neurocomputer; CCD cameras; color image scanner; HP plotter; color monitors; white light projection system; PCs; PUMA-560 robot; NOVA-IO robot]

D. Faculty - Group Leader: Prof. Chung Nim Lee

KOREA INSTITUTE OF SCIENCE & TECHNOLOGY (KIST), SYSTEMS ENGINEERING RESEARCH INSTITUTE (SERI), COMPUTER VISION GROUP

A. Research Areas

1. Image Processing System and Applications

   Satellite data processing
   Computer inspection
   Medical imaging
   CAD/CAM and graphics
   Automatic character recognition
   Fingerprint recognition

2. Research on Basic Software for Remote Sensing Utilizing Image Processing Systems

B. Projects (partial list)

1. Image processing system with microcomputer
2. Development of vectorized image processing software for the processing of remotely sensed data
3. Development of automatic testing system using computer vision and AI techniques
4. Development of weather satellite data analysis technique and workstation software for image processing
5. Development of automatic car license plate recognition system

C. Facilities (SUN workstations, IBM PC/AT based graphics systems, IBM PC-386 based graphics system, CRAY-2S/4-128, CYBER 960, Micro-VAX 11)

D. Researchers - 4 Ph.D., 4 M.S., 5 B.S.

FIRST NEW INFORMATION PROCESSING TECHNOLOGY WORKSHOP '91

The First New Information Processing Technology Workshop '91, held from 5-8 November 1991 in Yokohama, Japan, is briefly described.

by David K. Kahaner

INTRODUCTION

NIPT (New Information Processing Technology) was last year's name for a major 10-year Japanese computing project proposed by the Ministry for International Trade and Industry (MITI). This year's names are Real World Computing (RWC) and Four-Dimensional Computing (4DC). (Japanese scientists prefer RWC, and in subsequent reports I will use this name.) The project is in feasibility study now, and if deemed "feasible" (which appears likely) it will begin officially 1 April 1991 for a period of 10 years. The suggested budget is on the order of $40-50M per year. This is a large, but by Western standards not a huge, program, although it has high visibility, and participating in it is viewed as prestigious. MITI wants to make this an international program and has offered the possibility of participation to scientists outside of Japan. The purpose of the current workshop was to listen to proposals from interested scientists. The workshop was open to those scientists whose proposals had sufficiently interested members of the steering committee and to official observers. In addition to myself, two other U.S. scientists were observers:

Dr. Marc H. Brodsky
IEEE Technology Administration Fellow
U.S. Department of Commerce
Technology Administration
HCH Building, Room 4841
14th and Constitution Ave
Washington, DC 20230
Tel: (202) 377-4844
Fax: (202) 377-4362
E-mail: brodsky@watson.ibm.com

who is experienced in the area of opto-electronics, and

Dr. Barbara L. Yoon
Program Manager
Microelectronics Technology Office
DARPA/MTO
3701 North Fairfax Drive
Arlington, VA 22203-1714
Tel: (703) 696-2234
Fax: (703) 696-2201
E-mail: byoon@a.darpa.mil

who is experienced in the area of neural nets. As much as possible, we attended different sessions. The comments below represent our joint opinions, and these were almost entirely shared by the other Western attendees. I am very grateful for the enthusiastic assistance they provided to me, and I'm also happy to report that many of my Japanese colleagues were equally willing to provide me with frank and candid opinions.

Mr. Brian Enochs, representing the Science Counsellor in the U.S. Embassy, Japan, was also present at the plenary sessions.

Approximately 80 scientists attended this workshop as shown in Table 1. There were also seven or eight MITI representatives, two Japanese observers from the Electrotechnical Laboratory's (ETL) planning office, and three members of the secretariat from the Japan Information Processing Development Center (JIPDEC).

Proposals were received from Germany, Korea, Canada, Singapore, the United Kingdom, The Netherlands, and Italy, but not from the United States. The absence of proposals from U.S. scientists was a significant topic of conversation during the workshop, and I was asked about it repeatedly. There was a general feeling of disappointment about the lack of collaborations with U.S. scientists, but some of the Japanese scientists felt they had plenty of their own ideas. The Europeans, while mildly concerned about the implications, were hoping that this left a larger slice of the pie for them.

The U.S. Government has suggested an independent collaboration on a rapid prototyping optical fabrication facility along the lines of the MOS Implementation Service at the University of Southern California. [A brief description of the thinking that led to this decision is given in the 28 October 1991 edition of *New Technology Week* (NTW).] H. Fukuda, MITI, announced it was his opinion that the United States and Japan will choose to conduct joint optoelectronics research and development (R&D) under their bilateral Science and Technology Agreement and towards that end would conduct a feasibility study.

Table 1. Attendance at Workshop

Category	Participants	Observers	Proposals			
			Theory	Massively Parallel	Neural	Optical
Japanese University	16	0	2	3	2	5
Government Lab	5	6	1	1	0	0
Industry	38	0	14	8	7	8
Overseas University	8	0	2	3	2	1
Government Lab	9	1	3	2	1	2
Industry	0	0	0	0	0	0
Foreign Government Observers (U.S., Canada, Germany, Korea)		9				

There was no official European Community (EC) representation. Instead, R. Eckmiller (University of Dusseldorf, Germany) explained to the audience that the EC Commission had told him it wanted symmetric collaboration, i.e., university with university, industry with industry (if companies so desired), government institute with same, etc., and did not want oblique collaboration. It would also consider a totally vertical collaboration from basic research all the way to marketable product (that is, beyond prototype development). (Symmetric collaboration sounds great but might be difficult to achieve given the differences in research systems between Japan and the West. What about symmetric benefits?)

I asked about the budget for this program and was told that it would be of a similar order of magnitude as the ending 5th Generation project [Institute for New Generation Computer Technology (ICOT)], thus about $40-50M per year. However, the exact figures are not yet available, nor are the relative percentages for university, industry, government laboratory, and foreign participation. One source said the money would be divided several ways. About 25% would be designated for foreign groups as part of the "international cooperation." Of this, $100M, about two-thirds, was thought to be for the United States and one-third for the EC and Asian countries. (Now that the United States has declined to collaborate directly, it isn't clear how this will affect the funding.) The $400M would also be split about equally among four topics: (1) theory and new functions for application, (2) massively parallel systems, (3) neural computing systems, and (4) optical computing systems.

A very clear distinction was made between NIPT and the 5th Generation project. I quote this below.

Functional:

The characteristics of the fifth generation computer:

(1) To process the symbolic information such as characters and to make inference in accordance with the logical rules, typical of the syllogism.

(2) The applicable fields are the intellectual information processing fields such as the analysis of the gene arrangement, the case study, and judgment based on the provisions of the laws and regulations and judicial precedents.

The characteristics of the NIPT Program:

(1) To process a variety of information and to resolve such problems that are impossible or very difficult to be resolved in a logical manner.

(2) The applicable fields are the fields of the new information processing such as pattern information processing, resolution of the highly difficult problems, and intellectual robot, which need the functions of flexible recognition, problem solving, and control.

System:

The characteristics of the fifth generation computer:

(1) This system is the highly parallel system composed of the element processors, and each element processor works under the control of hierarchical distributed control.

(2) The parallel operating system and the application software systems are described in the logic programming language.

(3) The VLSI and ULSI technology are applied as the device technology.

The characteristics of the NIPT Program:

(1) The massively parallel system, neural system, and the integrated system are constructed and are composed of millions of element processors. Robust system composing technology and the adaptive control technology for load distribution to the element processors are needed.

(2) Important subjects are to develop the massively parallel language and the massively parallel operating system. In the languages the describing ability is requested to enable the direct mapping of the problem on the system and to enable the autonomous cooperative actions of each element processor. In the operating system, the learning function is requested to control the whole system in a robust and autonomous manner.

(3) In order to construct the system composed of millions of element processors, consideration should be made to the technology of integrated circuits to carry plural element processors on the wafer and the application of the optical device technology with ability of massively parallel transmission and processing of information.

In my earlier reports I have commented repeatedly on the vagueness of the proposed NIPT (RWC, 4DC) program. Some of this vagueness may have resulted in a rather imposing view of what might be accomplished. For example, in the NTW mentioned above, it is written that "the Japanese are looking for ways to make a million processor, ultra-supercomputer, artificially intelligent thinking machine." MITI's own documentation hopes that this program will be "a means of realizing real-world computing that flexibly deals with imperfect, ambiguous, and changing information in the actual world, and passes appropriate and advanced judgment and problem-solving." Some of the documentation provided at the workshop also describes impressive goals. However, based on the submitted workshop proposals, the fog is slowly lifting as scientists begin to specify the explicit research that they hope to perform. It is my opinion that what is likely to emerge is quite reasonable, and that in many ways the program is conservative.

DISCUSSION

In this workshop proposals were broken into one of four subgroups, Theory and Novel Functions for Applications, Massively Parallel Systems, Neural Systems, and Optical Computing Systems (corresponding to T, M, N, and O, respectively). I believe that this stems from NIPT views that show optical technology as a fundamental technology underpinning both a massively parallel and (perhaps equivalent) neural system which, in turn, uses new theory to help develop new and important applications. Earlier documents had listed eight basic areas with some overlap; at the moment these have been reaggregated into four. With the help of the authors, the organizers tried to place the proposals fairly, but several placed in T could have as easily been put into N. Nevertheless, at this stage it is fair to say that there is very little integration between the four sections, and this will be a major task for the steering committee. (This opinion was quite generally shared by the participants; some even wrote as much in their proposals.) Perhaps it will be impossible to do more than give lip service to this integration, as the time constants for some of the research proposals were vastly different. Also, as yet there has been no attempt to integrate the proposals within a subgroup, certainly the Western scientists had no idea of what they would hear when they arrived.

The workshop began with a half day of plenary talks in which the four subgroup moderators gave their views of the eventual research thrusts in their areas, followed by 2 days of four parallel sessions, one on each of the four subgroup topics. On the last day a general session gave the moderators an opportunity to present a very rough master plan for each group. These were done under a great deal of time pressure (the session moderators are to be congratulated for achieving as much as they did), but these plans had not been coordinated and I felt that they needed much further refinement.

I should mention that although referred to as proposals, in fact most of the presentations were more like extended abstracts, without budgets, specific task descriptions, milestones, evaluation criteria, etc. Individual proposal descriptions were labelled as not for distribution. However, proposal titles and authors were not so labelled and these are in the Appendix. Interested readers are encouraged to contact the authors directly for more detailed information.

My understanding is that the steering committee will now attempt to decide which of these are to be moved forward, and these individuals will be asked to produce more detailed proposals. I think there will be many changes resulting from the current workshop. Some changes were announced even before the workshop was ended. Original plans were to have two additional feasibility workshops, in January and March 1992. It is now the intention to have one more workshop during the week of 2 March, at which time an integrated master plan will be presented. Project funding will begin the following month. Most of the decision making will go on in executive sessions, and the general feeling among the attendees was that individuals with whom collaborations were to be established had already mostly been selected. There will certainly not be a refereeing process in the Western

sense; however, the committee members are very senior scientists and readers should expect that the projects funded will be internationally credible. It is not entirely clear, though, how new ideas that surface during the 10-year duration of the program will be handled. I mentioned above that participating in this project is a high prestige item. This was echoed by a German colleague who felt that the financial support, while welcome, was really incidental. It is presumably the reason that the Korean proposal in the Theory subgroup was presented with a clear statement that only technical collaboration, not financing, was being requested. In the Optical Computing Systems subgroup, another Korean proposal on Optical Neural Systems seemed to indicate an interest in obtaining advanced Japanese optical devices as part of the international collaboration. Similarly, a Singaporean was seeking funding but probably would be happy just to collaborate technically. There is also good reason to think that prestige, as well as being "plugged in," is a major factor in most Japanese company participation.

MITI has made significant efforts to make this a program that is not only focused on Japanese industry. In July 1991 ["NIPT Feasibility Study and Workshops," *Scientific Information Bulletin* **16**(3), 5-6 (1991)] I reported that there was a major change in the way ownership of intellectual property was to be handled, with equal sharing between the Japanese Government and the inventor. It is also important to note that for the NIPT project there is now the possibility that Japanese university researchers can obtain funding from MITI. This could supplement funding from the (much poorer) Ministry of Education. One Japanese professor told me that this possibility of new funding was the major reason he was participating. Another told me that this source of new Japanese Government funding for universities would be of most benefit to younger faculty whose connections have not been so well established. More senior faculty, he claimed, have many opportunities for support from government and industrial sources. At least one European observer felt that the Ministry of Education would not stand by while MITI infringed on its jurisdiction of university funding.

The most concrete of the sessions concerned massive parallelism. Here I was told repeatedly by attendees that the focus is that ETL wants to continue its research on generalizations of the dataflow model that it has been working on for some time and for which the laboratory has a great deal of hardware experience. They want to build a 10,000-processor 1-TFLOP machine within 5 years as a prototype and a one million processor machine within 10 years. As there are already commercial machines with tens of thousands of processors (albeit simple ones), this does not appear to be a revolutionary step, although there are many, many problems to be studied concerning the computing model, reliability, and software development. The emphasis in this development will be a machine that can adapt to various required computing paradigms and so will function as a general purpose resource. Nevertheless, the working language will probably be some type of parallel extended object-oriented language. I was told that at least one Japanese company proposal would likely be withdrawn (although they would probably continue as an industrial partner), as it seemed clear to the proposers that ETL had its own view of how it wanted to proceed. After listening to the individual proposals, the session moderator, Dr. T. Shimada of ETL, presented a draft master plan (of his session) to the entire workshop. This draft does not suggest that optics will play a major role, except perhaps at the level of interconnects. This is sensible, as the hope is to begin building in the next fiscal year, whereas optical technology, while very promising, does not seem to be at the same stage of readiness. During the final plenary session, the draft plan actually did not explicitly highlight bias towards a dataflow machine but listed dataflow as one option in a list of options that needs more study.

Expectations of the program, according to the steering committee, are still focused on integration of (imperfect) information, adaptation, learning, approximate optimization, etc. Specific functions that were mentioned in the overall plan include speech understanding based on constraint satisfaction, flexible action control in robots, as well as applications to massively parallel, integrated, neural, and optical systems, etc.

The theory session was composed of about 20 essentially independent proposals, ranging from a 50-year proposal from Mitsubishi research for computer vision understanding; R. Eckmiller's proposal to deal with international issues such as smog modeling, global warming, etc.; down to a 3-year proposal from Singapore's Institute of Systems Science (ISS) for development of what will essentially be a product. Most of these papers represented good science, but even if all are funded and all were to succeed nearly to their proposers' expectations, the fundamental goals of the program may not be attained. Thus readers should not expect that whatever hardware and software are eventually built within the scope of this program will result in a system that is able to realize when we are telling a joke. Further, it does not seem that the most advanced, hence ambitious, of the research from this subgroup could have much direct impact on the design of the massively parallel system, probably coming too late in the cycle.

I asked about computing resources that would be made available to collaborators in this project. (The a-building massively parallel system will not be ready at the early stages as a research tool for users.) The organizers have

not settled this question but spoke of making commercial parallel systems available and also of providing a high speed network for communication and experimentation among the participants.

The neural session resulted in a draft master plan stating that they hoped to build a 10-TCUPS machine in 10 years. Last spring, Hitachi demonstrated a working 2-GCUPS wafer scale neural system. Thus 10 TCUPS appears to be a realistic target within 10 years, and certainly not an unexpected one. One change coming out of the workshop was that this committee has decided not to validate the system on real applications but only on "novel functions for applications," i.e., application building tools.

The optical computing systems session emphasized the optical interconnect technologies and the supportive device and materials processing. The sentiment was that this type of work needed to be done before realistic sizings of processor architectures could be made. Of the 13 Japanese proposals, 8 were really expansions of and capitalization on existing industry (6) and university (2) optoelectronic device R&D. There was a ground swell of opinion that the session should report back only on devices for interconnects and leave the other two assigned topics (optical digital and optical neural) for other subgroups (namely, massively parallel and neural systems). The session moderator agreed with the technical reasoning, but said it would have to be discussed after the workshop. Virtually all the major Japanese companies, except NTT, were represented with these types of optical device proposals.

Appendix

PROPOSALS PRESENTED AT THE FIRST NIPT WORKSHOP 1991

Session T1 Theory and Models (1)

T1-1 Computational Learning Theory of Probabilistic Knowledge Representations
Abe, Naoki (NEC Corp., Japan) (ABE@IBL.CL.NEC.CO.JP)

T1-2 Ecological and Evolutional Computation Models for Massively Parallel/Distributed Systems
Matsuo, Kazuhiro (Fujitsu Laboratories Ltd., Japan) (MATSUO@IIAS.FLAB.FUJITSU.CO.JP)

T1-3 Pattern Recognition Using Neural Associative Memory
Lui, Ho Chung (National Univ. of Singapore, Singapore) (ISSLHC@NUSVM.BITNET)

Session T2 Theory and Models (2)

T2-1 Fundamental Research on Information Integration Technology Based on Multi-Neural Network
Matsuba, Ikuo (Hitachi Ltd., Japan) (MATSUBA@SDL.HITACHI.CO.JP)

T2-2 A Vision Processor in Neural Architecture
Banzhaf, Wolfgang (Mitsubishi Electric Corp., Japan) (BAN@RELACHE.ADM.CRL.MELCO.CO.JP)

T2-3 Hyper-Heterarchical System for Auditory Scene Understanding
Kawahara, Hideki (Nippon Telegraph and Telephone Corp., Japan) (KAWAHARA@SIVA.NTT.JP)

Session T3 Recognition and Understanding

T3-1 Sensory Integration
Sugie, Noboru (Nagoya Univ., Japan) (SUGIE@SUGIE.NUEE.NAGOYA-U.AC.JP)

T3-2 Research on Information Fusion Methods in Pattern Recognition/Understanding
Tsukumo, Jun (NEC Corp., Japan) (TSUKUM@PAT.CL.NEC.CO.JP)

T3-3 A Multi-Modal Human Interface
Chiba, Shigeru (Sharp Corp., Japan) (SCHIBA@TOKEN.SHARP.CO.JP)

T3-4 Action Image Database
Abe, Hasahiro (Hitachi Ltd., Japan) (ABE@CRL.HITACHI.CO.JP)

T3-5 Recognition of 3000 Chinese Characters Handwritten Kanji Characters
Muehlenbein, Heinz (GMD, Germany) (MUEHLEN@GMDZI.GMD.DE)

Session T4 Multimedia Information-Base and Interface

T4-1 Self-Organizing Information Base
Hirayama, Masaharu (Mitsubishi Electric Corp., Japan) (HIRAYAMA@SYS.CRL.MELCO.CO.JP)

T4-2 Multilingual Natural Language Interface/Interaction for Human and Computer
Ahn, Byung-Sung (Electronics and Telecommunications Research Institute, Korea) (D6000@KIET.ETRI.RE.KR)

T4-3 Some Novel Functions for the NIPT Computer Interface
Inoue, Hirochika; Sato, Tononasa; Hirose, Michitaka (Univ. of Tokyo, Japan) (INOUE@JSK.T.U-TOKYO.AC.JP)

T4-4 Self-Organizing Adaptive Mechanisms Based on Uncertain Information
Taura, Toshiharu (Nippon Steel Corp., Japan) (TAURA@ELELAB.NSC.CO.JP)

Session T5 Inference and Problem Solving

T5-1 Learning Neural Computers for Global Forecasting and Control - Theory and Applications
Eckmiller, Rolf (Univ. of Dusseldorf, Germany) (ECKMILLE@DD0RUD81.BITNET)

T5-2 Research on the Dynamic Inductive Inference
Sakurai, Akito (Hitachi Ltd., Japan) (SAKURAI@HARL.HITACHI.CO.JP)

T5-3 Coordinative Distributed Problem Solving Model by Structured Agents
Fukumura, Satoshi (Kawasaki Steel Corp., Japan) (FUKUMURA@SYSTEM.KAWASAKI-STEEL.CO.JP)

Session T6 Integrated Systems

T6-1 Development of a Flexible Hand-Eye Robot in Neural Architecture (refer to the proposal of T3-5)
Muehlenbein, Heinz (GMD, Germany) (MUEHLEN@GMDZI.GMD.DE)

T6-2 Human Interface Using Artificial Reality
Kurihara, Tsuneya (Hitachi Ltd., Japan) (KURIHARA@CRL.HITACHI.CO.JP)

T6-3 Research on Flexible Information Processing Models - An Autonomous Growth System
Asakawa, Kazoo (Fujitsu Laboratories Ltd., Japan) (ASAKAWA@FLAB.FUJITSU.CO.JP)

Session M1 Architecture (1)

M1-1 Research and Development on Composite Super-Fine-Grain Architecture for Massively Parallel Computing Systems
Hiraki, Kei (Univ. of Tokyo, Japan) (HIRAKI@IS.S.U-TOKYO.AC.JP)

M1-2 A Dataflow Massively Parallel Computer
Shimizu, Uasahisa (Sanyo Electric Co. Ltd., Japan) (SHIMIZU@EDDEN.HIRAKATA.SANYO.CO.JP)

M1-3 Research and Development of a Massively Parallel Architecture Based on the Extended Dataflow Model
Yamaguchi, Yoshinori (ETL, Japan) (YAMAGUTI@ETL.GO.JP)

Session M2 Architecture (2)

M2-1 Adaptive Massively Parallel Machines
Koike, Nobuhiko (NEC Corp., Japan) (KOIKE@CSL.CL.NEC.CO.JP)

M2-2 A Massively Parallel Machine with Optical Interconnection
Oyanagi, Shigeru (Toshiba Corp., Japan) (OYANAGI@ISL.RDC.TOSHIBA.CO.JP)

M2-3 Massively Parallel Image Processing Sub-System
Mizoguchi, Masanori (NEC Corp., Japan) (MIZO@PAT.CL.NEC.CO.JP)

Session M3 Model

M3-1 Self-Modifiable Computation Models for Massively Parallel/Distributed Systems
Tanaka, Jiro (Fujitsu Laboratories Ltd., Japan) (JIRO@IIAS.FLAB.FUJITSU.CO.JP)

M3-2 Development, Implementation, and Validation of a Programming Model and Programming System for Massively Parallel Computers
Giloi, Wolfgang (GMD, Germany) (GILOI@KMX.DBP.DE)

Session M4 System and Environment

M4-1 Network Supercomputing
Muraoka, Yoichi (Waseda Univ., Japan) (MURAOKA@WUCC.WASEDA.AC.JP)

M4-2 A Programming Environment Generator Parameterized with Architectures and User Interfaces OR How to Generate Dedicated Interactive Systems for Existing and Future Languages and Architectures
Kilnt, Paul (Centrun Voor Wiskunde en Informatice, Netherlands) (PAULK@CWI.NL)

M4-3 A Parallel Processing System for Multiple Computer Paradigms
Lee, Hoon Bock (Electronics and Telecommunications Research Institute, Korea) (HBLEE@KIET.ETRI.RE.KR)

M4-4 Architectures for Massively Parallel Computing
Maresca, Massino (Dist-Univ. of Genoa, Italy) (MM@DIST.UNIGE.IT)

Session M5 Language

M5-1 Design and Implementation of Programming Languages for Massively Parallel Computing Systems--Concurrent Object-Based Layered Approach
Yonezawa, Akinori (Univ. of Tokyo, Japan) (YONEZAWA@IS.S.U-TOKYO.AC.JP)

M5-2 Research on Object-Oriented Model for Massively Parallel Processing
Nakashina, Hiroshi (Mitsubishi Electric Corp., Japan) (HIROSHI@ISL.MELCO.CO.JP)

Session M6 Application

M6-1 Abstract Learning Machine for Super Parallel Computers
Refenes, Paul (Univ. College London, U.K.) (REFENES@CS.UCL.AC.UK)

M6-2 Dynamical-Simulation of Microscopic Worlds on Massively Parallel Systems
Ihara, Shigeo (Hitachi Ltd., Japan) (IHARA@HCRLGW.CRL.HITACHI.CO.JP)

M6-3 PART-DBS: PArallel and Real-Time DataBase Systems
Teranaka, Katsuni (Nippon Telegraph and Telephone Corp., Japan) (TERANAKA@SYRINX.NTT.JP)

M6-4 Research of Direct Mapping Paradigm
Tanaka, Hidehiko (Univ. of Tokyo, Japan) (TANAKA@MTL.T.U-TOKYO.AC.JP)

Session N1 Neural Model (1)

N1-1 Feedback Learning of Recurrent Neural System
Okabe, Yoichi (Univ. of Tokyo, Japan)

N1-2 Achieving a System That Grows Autonomously
Asakawa, Kazoo (Fujitsu Laboratories Ltd., Japan) (ASAKAWA@FLAB.FUJITSU.CO.JP)

N1-3 Distributed Learning Control Mechanisms for Modularized Neural Networks
Shinohara, Katsunori (Nippon Telegraph and Telephone Corp., Japan) (KATSU@NTTHIF.NTT.JP)

Session N2 Neural Model (2)

N2-1 Integrated Information Processing Technology
Nishiaura, Kazuo (Toshiba Corp., Japan) (KAZUO@SSEL.TOSHIBA.CO.JP)

N2-2 Neural Logic Networks
Shen, Zuliang (National Univ. of Singapore, Singapore) (ZULIANG@ISS.NUS.SG, ISS@NUSVM.BITNET)

N2-3 Machine Learning for Optimal Self-Organization
Refenes, Paul (Univ. College London, U.K.) (REFENES@CS.UCL.AC.UK)

Session N3 Neural Application

N3-1 Cooperative Problem Solving Based on Symbolic Information Processing System and Neural Network System
Kinoshita, Tetsuo (Oki Electric Industry, Japan) (KINO@OKILAB.OKI.CO.JP)

N3-2 Multi Agents Using Neural Systems
Hoshino, Seizo (NKK Corp., Japan) (HOSHINO@CSRD.NKK.CO.JP)

N3-3 Recognition and Understanding Based on Large-Scale Neural Network Architecture--Realization of Flexible Human Interface
Togawa, Funio (Sharp Corp., Japan) (TOGAWA@CRL-SP.SHARP.CO.JP)

Session N4 Neural Hardware

N4-1 Million Neuron Parallel Processor
Yamada, Hinoru (Hitachi Ltd., Japan) (YAMADA@CRL.HITACHI.CO.JP)

N4-2 Modular Architectures for Electronic Neuro-Computers
Lee, Son-Young (Korea Institute of Science and Technology, Korea) (SYLEE@EEKAIST.KAIST.AC.KR, SYLEE@KUMGANG.KAIST.AC.KR)

N4-3 Parallel Distributed Processing in Neural Systems Composed of Analog Elements with Chaotic Dynamics
Aihara, Kazuyuki (Tokyo Denki Univ., Japan) (AIHARA@DENDAI.AC.JP)

Session O1 Optical Interconnection (1)

O1-1 Electro-Photonic Processor Network
Kubota, Keiichi (NEC Corp., Japan) (KUBOTA@OEL.CL.NEC.JP)

O1-2 A Research and Development of Devices for Intelligent Optical Interface
Ishida, Koji (Hitachi Ltd., Japan)

O1-3 2-Dimensional Parallel Optical Interconnection for Massively Parallel Computing Systems
Nakamura, Masaru (Toshiba Corp., Japan)

Session O2 Optical Interconnection (2)

O2-1 Multi-Dimensional Opto-Electronic Interconnection: A Hardware for Parallel and Distributed Optoelectronic Processing
Kamijoh, Takeshi (Oki Electric Industry Co. Ltd., Japan) (KKAMIJO@HILAB.OKI.CO.JP)

O2-2 Research on Super-Multiplexing Optical Interconnections
Ishikana, Hiroshi (Fujitsu Laboratories Ltd., Japan)

O2-3 Optical Control of High Speed Digital Electronics for Interconnecting Interfaces and Massively Parallel Systems
Kaniya, Takeshi (Univ. of Tokyo, Japan)

Session O3 Optical Digital System (1)

O3-1 Research on Integrated Parallel Optical Computers and Parallel Programming
Ichioka, Yoshiki (Osaka Univ., Japan)

O3-2 Stacked Optical Computing System
Takeuchi, Yoshinori (Matsushita Research Inst. Tokyo Inc., Japan) (TAKE@TRL.MEI.CO.JP)

O3-3 Multi-Dimensional Optical Computer
Yatagi, Toyohiko (Univ. of Tsukuba, Japan) (YATAGI@OPTLAB.BK.TSUKUBA.AC.JP)

Session O4 Optical Digital System (2)

O4-1 Optically Coupled Three-Dimensional Common Memory
Koyanagi, Mitsunasa (Hiroshima Univ., Japan) (KOYANAGI@SXSYS.HIROSHIMA-U.AC.JP)

O4-2 Research and Development of 3D-Integrated Stacked Optical Devices for Surface-Emitting Lasers
Ibaraki, Akira (Sanyo Electric Co. Ltd., Japan) (S53IBARAKI@HR105.AL.SANYO.CO.JP)

O4-3 Digital Optical Image Processing
Digital Optical Numerical Computers
Micro-Optics
3D-Integration of Optical Components
Brenner, Karl-Heinz (Univ. of Erlangen, Germany)

Session O5 Optical Neural System

O5-1 Optical Neurocomputing - Device and Architecture Technologies
Kyuma, Kazuo (Mitsubishi Electric Corp., Japan) (KYUMA@QUA.CRL.MELCO.CO.JP)

O5-2 Real-Time Optical Neurocomputing System with Learning Capabilities
Ishikawa, Masatoshi (Univ. of Tokyo, Japan) (ISHIKAWA@K2.T.U-TOKYO.AC.JP)

O5-3 Modular Architectures for Electro-Optic Neural Networks
Lee, Son-Young (Korea Institute of Science and Technology, Korea) (SLEE@EEKAIST.KAIST.AC.KR, SYLEE@KUMGANG.KAIST.AC.KR)

O5-4 Adaptive Optical Processing for 3D Vision
Chrostowski, Jacek (Institute for Information Technology, Canada)

COMPUTER SECURITY IN JAPAN

The state of progress in computer security activities in Japan is assessed. Attendance at the Tokyo Symposium on Information Security and industrial visits showed that the Japanese are at an early stage of development in this area, probably because of different social conditions from the West. However, as part of their vision of "global informatization," they are now making efforts to bring computer security up to a similar level to the West.

by Jonathan D. Moffett

INTRODUCTION AND DISCUSSION

This is a report on a short trip to Japan to study progress in Japanese computer security. On 17 and 18 October 1991 I attended the International Symposium on Information Security in Tokyo, organized by the Japan Information Processing Development Center (JIPDEC). In addition, I arranged visits to the research laboratories of Fujitsu, NEC, and Sony.

I found the state of development of computer security at an earlier stage than I had expected from progress in other areas of computing. To illustrate this, a survey of 217 members of the Fujitsu Large System Group (mainframe users) showed that only 44% at present control access to files using an access control system, with a further 31% planning to do so soon. So 25% of this sample of mainframe users have no plans to introduce file access control. This is only one statistic, selected from a wider survey, but it is consistent with a number of conversations that I had and with the tone of the Information Security Symposium. This was a very high level meeting, but its program showed that Japan is a country that has not advanced very far in the development of computer security. The program contents were rather general and 9 out of 13 speakers were Westerners.

An explanation for these features can be found in the introduction to the announcement of this symposium: "Social stability cannot be maintained in an age of global informatization unless all countries uniformly adopt the same level of minimum security measures." The Japanese believe that they have less of a computer security problem than Western countries, but that they cannot isolate themselves from global systems, and so they must bring their own security up to an adequate level. Some facts are clear: Japan has a high rate of natural disasters (earthquakes and typhoons) and a very low reported crime rate. (Skepticism about the rate of unreported crime should be tempered by the fact that even the murder rate, which we can assume to be reasonably well reported, is only about 25% of that in Europe.) There has, therefore, probably been much less need in the past for computer security than in Western countries, except for physical measures to deal with natural disasters.

The Ministry of International Trade and Industry (MITI) issued Computer Systems Security Guidelines in 1977 and has updated them twice since. I was told that they are mainly concerned with physical security. They issued System Auditing Guidelines in 1985. The first overt official response to technical computer insecurity problems was in 1990, when Computer Virus Measures Guidelines were published. Viruses have been the main publicly discussed "technical" problem, as can be seen from the program of the symposium. However, there appears to be a low level of installed security to deal with network hackers, and it would be surprising if international hackers had not attempted to penetrate Japanese networks, and succeeded. Indeed, there is reason to think that they have.

There is one exception to the relatively low level of security awareness and progress, and that is in the area of encryption. Every single one of the papers that I have been given is concerned with the design or use of encryption systems. I can only speculate why this should be the case, since it is inconsistent with the drive of the symposium, which was towards a more rounded, management attitude to security. Perhaps it only reflects the tradition of all research establishments to pursue what interests the researchers rather than what the market immediately requires.

If this were a Western symposium, one might be tempted to view the expression of unfulfilled intentions as an alternative to action rather than a plan for it. However, the Japanese have a

formidable track record of achieving their stated intentions, and it is reasonable to assume that they will do so in this case also. The plans were most clearly stated by Toshio Hiraguri's "Fujitsu Direction for Computer Security":

- Supply of products and functions which satisfy the demand for security
- Training
- Contribution to standardization activities
- Certification and evaluation of products

The achievement of these goals, by Fujitsu and others, will put Japan back on the mainstream of computer security in developed countries.

INTERNATIONAL SYMPOSIUM ON INFORMATION SECURITY IN TOKYO

At this symposium about 1,000 delegates attended. The great majority were Japanese. The symposium consisted of a first day with four keynote speeches after the introductions and a second day with three parallel sessions, each of three speeches and a panel session.

The symposium had several notable features. First, it was a very high level meeting. The Minister of International Trade and Industry was slated to open it, although in the event he sent his deputy. The President of NEC and the Managing Director of Fujitsu gave full-length talks. An impressive array of Americans and Europeans was brought in. Second, a glance at the program showed that this was a symposium for a country that has not gotten very far along the road of development of computer security. Apart from viruses (presumably brought in as much because they are a fashionable security concern, easy for an outsider to relate to, as for their real threat to computing), all of the talks were related to security management rather than technical issues. The subjects covered were those that are natural for a country that is about to come to terms, in a serious way, with computer security: risk assessment, security management, and promotion of security awareness. Third, 9 out of 13 speakers were Westerners. Japan has not yet gained the expertise to be able to provide enough speakers with the requisite experience for a meeting of this kind. True, this was an international symposium, but there can be no doubt that there would have been a higher proportion of Japanese giving talks if this had been possible.

There were three Japanese speeches, by the President of NEC, the Director of MITI's Information Service Industry Division, and the Managing Director of Fujitsu Ltd., which were useful for assessing their view of the current situation and future plans.

There was a high degree of overlap in their contents, and I got the following message from each. Japan has historically been a country with a low crime rate and a high vulnerability to natural disasters (earthquakes and typhoons). The computer security measures in the past have been addressed to these weaknesses. However, the "Information Society" is becoming global in scope, and it is therefore necessary for the Japanese to address the computer security problems that have up to now been mainly of concern to the West. This is because global communications mean that global systems must have a consistently high level of security, and in any case it is impossible to isolate Japan from problems imported from the West, such as viruses. Japan will therefore study what needs to be done, including Western experience. It will create standards that are compatible with, but not necessarily identical to, those in the West, and will take the necessary actions to provide security in its products.

My overall impression was of an event that is designed to motivate activity in this area and to leave none of the delegates in any doubt that this is an area of work that they must take seriously from now on.

INDUSTRIAL VISITS

Fujitsu

On 14 October 1991 I visited Fujitsu Laboratories in Kawasaki. My host was Ryota Akiyama, a senior researcher. I also spoke with Naoya Torii (researcher) and Haruki Tabuchi (a computer systems development manager). Akiyama and Torii gave me copies of two published papers (Ref 1 and 2) and told me about their work on an ID-based file security system. Its aim is to integrate login control, file access control, and encryption of data communication by an ID-based key management system. It is an interesting attempt to take an integrated approach, but it seems to have potentially severe performance problems when used in conjunction with large files. Also, there had been little consideration at this stage of how it would fit into a heterogeneous open-system world. It is a research project that appears at present to be some distance from the market. Akiyama and Torii also gave me a brief description of a network security module, to be connected to the extension bus of a Fujitsu PC, for network security and data protection. It is to be demonstrated at Asiacrypt '91. [Asiacrypt '91 is an English language symposium on encryption to be held 11-14 November 1991 in Fujiyoshida (at the foot of Mt Fuji).]

Tabuchi took a lively part in the discussions, and I had further conversations with him at the security symposium. He takes a direct practical interest in how to deliver security to customers and raise their awareness of its importance. He expressed interest in risk analysis methods, data protection

legislation, and assurance of security by formal specification methods.

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NEC

On 14 October 1991 I also visited NEC Laboratories, where my hosts were Katsuhiro Nakamura (senior manager) and Eiji Okamoto (research manager). Okamoto explained his work on encryption, which appears to be well thought-out and serious (Ref 3). All encryption is by software on the grounds of expense. Separate algorithms are used for data and key encryption. The data encryption algorithm is proprietary, designed tor high performance, capable of 100 KB/s throughput. The key encryption algorithm is a modification of RSA, designed to avoid a directory of public keys, described in the paper.

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Sony

On 15 October 1991 I visited Sony Computer Science Laboratory, much smaller than the Fujitsu or NEC laboratories. It has been described in a previous *Scientific Information Bulletin* article [D.K. Kahaner, "Sony Computer Science Laboratory," 15(4), 61-65 (1990)]. My host was Nobuhisa Fujinami, a researcher. They are working on the Muse operating system, a research system being developed during a 5-year project due to be completed in 1993. They are currently at the stage of implementation of a prototype and preparing for the implementation of version 1.0. An outstanding issue is that of cryptographic communication and authentication. At this stage they are still defining the issues in this area and are a long way from solving them. Security is not at the top of their list at present, because issues such as object identification schemes and dynamic configuration are seen as preceding it. I had the impression that they would reach the end of this project without necessarily having reached a final solution to system security.

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Jonathan Moffett graduated from Trinity College, Cambridge, in 1961 with a degree in mathematics. After a background as systems consultant on large commercial systems he has been a computer security specialist since 1978. He was computer security advisor for Esso UK and Esso Europe Inc. and has acted as consultant on computer security for banks and other commercial organizations. Dr. Moffett completed his Ph.D. in computer science in 1990 at the Department of Computing at Imperial College, University of London. He is currently a research associate at Imperial College, working in the area of distributed system management and concentrating on security management. Dr. Moffett is a member of the British Computer Society, a Fellow of the Association of Certified Accountants, and a Chartered Engineer. His research interests include security and control in distributed systems, formal representation of organizational structures, and decision making in conditions of uncertainty.

JAPANESE ADVANCES IN FUZZY SYSTEMS AND CASE-BASED REASONING

This article presents a survey and assessment of fuzzy systems and case-based reasoning research in Japan.

by Daniel G. Schwartz

REPORT SUMMARY

During this past summer (1991), I spent 2 months on an appointment as Visiting Researcher at Kansai University, Osaka, Japan, and 5 weeks at the Laboratory for International Fuzzy Engineering Research (LIFE) in Yokohama. Part of the expenses for the time in Osaka, and all expenses for the visit at LIFE, were covered by the Office of Naval Research (ONR). While there I met with most of the key researchers in both fuzzy systems and case-based reasoning. This involved trips to numerous universities and research laboratories at Matsushita/Panasonic, Omron, and Hitachi Corporations. In addition, I spent 3 days at the Fuzzy Logic Systems Institute (FLSI), Iizuka, and I attended the annual meeting of the Japan Society for Fuzzy Theory and Research (SOFT-91) in Nagoya. The following report elaborates what I learned as a result of those activities.

There is no doubt that Japan has pulled far ahead of the United States and other Western nations in implementing the theory of fuzzy sets and systems. Of primary significance is development of the fuzzy logic controller, wherein the traditional proportion integral derivative (PID) controller is replaced with a fuzzy rule based expert system. The main advantage of the fuzzy logic controller is its ability to handle real-time nonlinear control problems. The results achieved so far clearly portend a minor revolution in the field of automated control. Implementations of the underlying ideas have been realized in both software and hardware, using both digital and analog devices, and there already are several dozen commercial products that utilize these control techniques. Very recently, researchers at the Tokyo Institute of Technology have succeeded in fully automating the hovering operation in a model helicopter, a task well known for its inherently difficult stability problems. U.S. patents have been obtained by Japanese corporations for various very large scale integration (VLSI) fuzzy inference chips, and Omron Corporation alone boasts over 700 patents either obtained, pending, or in application. The potential variety of applications for these ideas seems virtually unlimited.

Fuzzy technology is at the same time being developed in other directions. Hitachi Corporation markets a fuzzy expert system shell that has now sold over 2,000 copies, and research directed at expanding such systems' reasoning capabilities is ongoing in numerous universities, corporations, and research institutes. In recent months, even the more traditional Japanese artificial intelligence (AI) community has begun to recognize the potential value of fuzzy logic as a model of natural human reasoning.

Also in progress is development of a fuzzy flip-flop circuit, which shows promise of providing the basis for a general-purpose fuzzy computer. The fuzzy flip-flop can include the conventional binary flip-flop as a special case. Other recent developments include some experiments with an optical fuzzy inference device, which performs the fuzzy inference operation at a much higher speed than electronic VLSI circuits. Overall, Japan's advances in these areas are impressive and suggest many fruitful lines for future research.

Case-based reasoning (CBR) is a relatively new idea that currently has only a small cadre of Japanese proponents. The researchers in this area share the view of their American counterparts that CBR holds promise of alleviating some of the knowledge acquisition problems shared by other knowledge representation schemes. As an approach to simulating natural human reasoning from remembered experiences, CBR is implicitly also a learning paradigm. Japanese scientists are currently exploring applications of CBR in such areas as machinery configuration, industrial process diagnosis, information retrieval, and complex system simulation. There is also the possibility of using CBR techniques in computer-aided software engineering, for both the design and development phases of complex software systems. Research in these areas is still in the formative stages, however, and further study will be needed before these ideas manifest in concrete applications.

INTRODUCTION

Today in Japan we are witnessing what is likely to become a textbook example of how a theory is turned into applications. What is especially compelling about this particular example, moreover, is that the applications themselves confirm the intuitions held 25 years earlier by the theory's originator. In 1965, when Lotfi Zadeh at UC Berkeley's Department of Electrical Engineering published his first paper on fuzzy sets, he was implicitly advancing the thesis that one of the reasons humans are better at control than currently existing machines is that they are able to make effective decisions on the basis of imprecise linguistic information. Hence it should be possible to improve the performance of electromechanical controllers by modeling the way in which humans reason with this type of information.

The theory developed slowly at first, but by the early 1970s it had attracted a small international following. This included a number of Westerners, mostly mathematicians, and a small number of Japanese engineers. In those days, the interest was spurred primarily by intellectual curiosity, although even then there was a pervasive belief in the theory's ultimate applicability. During this time, investigations focused mainly on the mathematical properties of fuzzy sets and closely related notions, and numerous variants of fuzzy logic were explored.

By the late 1970s, interest in fuzzy systems had grown rather explosively, attracting many researchers from around the world and spawning bibliographies with citations numbering in the thousands. Still, most of the work was theoretical. The main topics included fuzzy knowledge representation and reasoning schemes, the philosophical ramifications of fuzzy logic and fuzzy set theory, fuzzifications of various branches of classical mathematics, and several foundational challenges posed by probability theorists and the classical AI community. Partly in response to this, Zadeh put forth "possibility theory," which showed how the fuzzy sets model of natural language reasoning could be provided with an intuitively acceptable foundation, and at the same time explained how this was distinct from probability theory.

Although most of the work at this time was still largely theoretical, the seeds of a few applications were planted. The first fuzzy logic controller was produced in 1975. Soon thereafter Zadeh began underscoring the opportunities for using fuzzy sets in the newly emerging field of expert systems. Now, primarily in Japan, we find that this has begun to manifest in a variety of commercial applications, and it would seem that this is only the beginning. Based on recent Japanese successes, it seems virtually assured that fuzzy sets will become essential ingredients in most future systems of expert reasoning and automated control.

Because of its importance in the current state of fuzzy systems research, all of the next section is dedicated to the subject of fuzzy logic controllers. The remaining sections survey other developments in a report on activities at various so[illegible]ies, research institutes, universities, and corporate laboratories; cover current activity in case-based reasoning; and offer a few summary reflections, including conjectures on why the Japanese have outstripped their Western counterparts in this domain, together with some suggestions on what the United States might do to catch up.

FUZZY CONTROL

The first paper describing a fuzzy logic controller was published by E.H. Mamdani and S. Assilan of Queen Mary College, England, in 1975. For their study, they chose the example of a simple steam engine. The controller for this engine has four input variables--pressure error, speed error, change in pressure error, and change in speed error--and two output variables--heat change and throttle change. The essential idea was strikingly simple. In the conventional PID controller, the system being controlled is modeled analytically by a set of differential equations whose solution tells what adjustments should be made to the system's control parameters for each type of system behavior. The proposed fuzzy logic controller, on the other hand, was based on a logical model that directly represents the thinking processes that a human operator might go through while controlling the system manually.

Such a logical model is expressed as a set of inference rules of the form "if behavior variable B (input to the controller) is observed to be in the state X, then change control parameter C (output from the controller) by an amount Y" (or perhaps to state Y). The model earns the designation "fuzzy" by virtue of its specifying the amounts X and Y linguistically, using terms like "positive big," "positive medium," "positive small," "no change," "negative small," etc., where each such term is represented as a fuzzy subset of the associated measurement domain.

[Given a measurement domain D, a fuzzy subset A of D is represented as a function mu_A which maps D to the unit interval [0,1], whereupon the real number mu_A(x) is the degree of membership of x in D. In case the fuzzy set A is being used as the meaning of a linguistic term tau, then this degree of membership is further interpreted as a degree of "compatibility" of x with tau. For example, suppose D is a range of pressures measured in pounds per square inch. Then some fuzzy subset PB of D might be given as the meaning for the term "positive big," in which case, for each pressure x, mu_PB(x) becomes the degree of compatibility of x with the designation "positive big".]

Many approaches have been developed for expressing such inference rules mathematically, for choosing an appropriate rule set, for defining the fuzzy sets that are to serve as meanings for the linguistic terms, for combining results when more than one rule might apply, and so on. In Mamdani and Assilan's experiment, the inference rules were expressed in the manner proposed by Zadeh's works, the rules were selected in accordance with Zadeh's "compositional rule of inference," and the fuzzy results from multiple rules were combined using a kind of generalized averaging technique, after which one could easily extract a precise (nonfuzzy) value as the controller's final output. The averaging technique was applied only after the entire set of inference rules had been "tuned," however, so as to eliminate contradictory results. That is, the rule set was manipulated so that it would not be possible for one rule to conclude, for example, that the throttle should be moved in the positive direction, while another would conclude that should it be moved in the negative direction. This tuning process was accomplished by simply checking all possible output combinations and dealing in an appropriate manner with those that were potentially contradictory. The task was not exceptionally difficult, since the controller employed only a small number of rules--15 for the heater and 9 for the throttle.

This experiment, together with a few closely related experiments conducted by others, clearly demonstrated that this was an effective means of automated control. Indeed the logical models have a definite advantage over the traditional analytical models in that (1) they work well even when the relation between the controller's input and output variables is nonlinear, and (2) they are much more robust with respect to changes in the controlled system's parameters, e.g., the desired engine speed. It is generally held that classical PID controllers cannot be designed for the case of nonlinear control and that, even for linear control, they typically must be designed anew whenever one resets the basic system parameters.

Following this work, Mamdani tried unsuccessfully to secure funding for his research from the British granting agencies. Unable to obtain any support, he ultimately abandoned this line of investigation to pursue other opportunities. His work did not go unnoticed in Japan, however, and approximately 10 years later, Hitachi Corporation announced the Sendai Railway as the first fully automated subway system employing a fuzzy logic controller. Hitachi had for many years been in the business of designing subway control systems, particularly safety mechanisms, and so this next step was a natural evolution of its existing product lines. The new system controlled all aspects of accelerating to speed and braking for corners or stopping at the next platform, so that the only human operator served essentially as a conductor, watching out for passengers' safety while getting on or off the train.

Implementation of the Sendai fuzzy controller was largely due to Seiji Yasunobu of Hitachi's Systems Development Laboratory. Although this work was derived from that of Mamdani, Yasunobu's approach differed in two important respects. First, while he retained the use of fuzzy sets for defining the meanings of the needed linguistic terms, his rules were crafted through a more ad hoc trial-and-error methodology, rather than using the compositional inference technique. This evidently was because rote application of the latter did not produce the desired relations between rule premises and conclusions. An ad hoc approach was feasible since the logical part of the system used a mere nine inference rules--five for accelerating and/or maintaining constant speed and four for braking. Second, he introduced a new method for combining the results of multiple rules and extracting a precise output. This approach, now known as the "centroid method," has become the standard solution for this problem.

Through simulations, Yasunobu demonstrated that the fuzzy logic controller was superior to the conventional PID controller along several key parameters, including accuracy in stopping at the platform, rider comfort (jerkiness of acceleration and braking), and fuel economy. He proposed his ideas to Hitachi in 1983, published his simulation results in 1985, and the Sendai Subway opened in 1987. It has been performing satisfactorily ever since.

Also in 1987 another event occurred which, together with the Sendai Railway, served as the catalyst for an explosion of interest in the subject of fuzzy control. This was Takeshi Yamakawa's demonstration of his inverted pendulum experiment at the Second Congress of the International Fuzzy Systems Association (IFSA-87), held in Tokyo. The inverted pendulum is a classic control problem, amounting to balancing a vertical pole that is attached to a belt by a hinge, so that the pole can fall to the right or the left. The idea is to monitor the angular position and speed of the pole and move the belt to the right or left accordingly, so as to maintain the pole in an upright position. The problem becomes more difficult as the pole becomes shorter and/or is reduced in total mass, since the required response times decrease in proportion to the square of the amount by which either height or mass is reduced.

Yamakawa's controller featured two types of VLSI chips of his own design. One was a fuzzy rule chip, which directly implements Zadeh's compositional rule of inference, and the other was a defuzzifier chip, which calculates the centroid of a collection of fuzzy membership functions. This may be contrasted with Mamdani's approach, wherein he precomputed the results of the compositional inference rule for a limited set of possible inputs and then used these

computations to form the rules actually appearing in his controller. The reason for this approach is that the compositional rule involves a matrix operation that cannot normally be performed fast enough on a standard digital computer. In Yamakawa's system, this problem was overcome by designing a chip specifically for this computation. An important feature of Yamakawa's approach, moreover, is the use of analog techniques, rather than digital. This was done because the elementary operations employed in the compositional rule of inference, and for the most part also in the defuzzification operation, are the arithmetic max and min, which can be implemented so as to run much faster on an analog device.

The controller presented at IFSA-87 used seven rule chips and one defuzzifier chip, and it demonstrated balancing response speeds approaching 100 times faster than those heretofore accomplished by a conventional PID controller. This result generated a flurry of commentary, including a few negative responses both from without and within the fuzzy systems community. The latter stemmed from the fact that the controller only maintained vertical, and not horizontal, stability of the inverted pendulum, whereas the classical problem entails both. Moreover, it was shown rather easily that, with that particular system, accomplishing both was impossible. Hence Yamakawa suffered criticism for publishing results that were as yet incomplete.

Less than a year later, however, Yamakawa was able to vindicate himself by producing a system with only four additional rule chips that performed both vertical and horizontal stabilization at the same speed as before. Since that time, Yamakawa has demonstrated the robustness of his system for nonlinear control by attaching a small platform to the top of the inverted pendulum, on which is then placed a wine glass filled with liquid, or even a live white mouse. The controller nicely compensates for the turbulence in the liquid, as well as the totally erratic movements of the mouse. Thus in the latter, a claim could be made for executing control even beyond nonlinearity and into truly random or "chaotic" domains.

Before reporting these results, Yamakawa applied for patents on his chips in Japan, the United States, and several European nations. He then proceeded to trade his patents to several Japanese corporations in return for their subsidizing a laboratory in which he could continue his research. (Japanese university professors are not allowed to make money outside of their duties as a faculty member.) Omron, a major producer of second tier electronic devices, was a major proponent and has subsequently decided to invest heavily in fuzzy control. Omron has been rapidly expanding on Yamakawa's original designs, producing a host of new chips, both analog and digital, and churning out scores of applications. Due to [illegible]urchase of Yamakawa's patents, in [illegible]t, it has recently become the first Japanese corporation to ever obtain a U.S. patent. As of July 1991, Omron boasted 700 patents for fuzzy logic devices either acquired, pending, or in application. Most of these devices either have appeared, or will appear, in commercial products. Three or four dozen alone are earmarked for use in automobiles, e.g., antilock brakes, automatic transmissions, impact warning and monitoring, windshield washers, and light dimmers. Omron is also incorporating fuzzy control into products for use in industrial and manufacturing processes.

Numerous commercial products using fuzzy technology are currently available in Japan, and a few are now being marketed in the United States and Europe. Canon uses a fuzzy controller in the autofocus mechanism of its new 8-mm movie camera. The Matsushita/Panasonic "Palmcorder," currently being promoted on U.S. television, uses fuzzy logic for image stabilization. This happens to be the very first video camera to appear with image stabilization capability. Matsushita, Hitachi, Sanyo, and Sharp now have their own "fuzzy washing machine," which automatically adjusts the washing cycle in response to size of load, type of dirt (soil versus grease), amount of dirt, and type of fabric. In Matsushita's machine, the type and amount of dirt are detected by means of light sensors, which also use fuzzy controls. Other products using fuzzy control include vacuum cleaners, air conditioners, electric fans, and hot plates. One senses that the possibility for such applications is virtually endless. Another, now famous, application is a road tunnel ventilation system, also designed by Yasunobu at Hitachi.

A somewhat more ambitious project is the voice-controlled helicopter being developed by Michio Sugeno at the Tokyo Institute of Technology. Here the objective is to develop a helicopter that responds to voice commands like "hover," "forward," "back," "left," "right," "up," and "down," where each such operation is handled automatically via fuzzy logic. Sugeno has successfully accomplished all functions with a 1-meter model and is now working on a 3-meter model. As of August, he had achieved hovering and was confident that the other operations could be accomplished as well. Hovering is well known to be a very difficult stability problem; beginning helicopter pilots typically train for weeks before being able to do this manually. Hence, successfully automating the hovering operation is in itself a very impressive result. [See the article by D.K. Kahaner and D.G. Schwartz, "Fuzzy Helicopter Flight Control," *Scientific Information Bulletin* 16(4), 13-15 (1991).]

These few examples illustrate the variety of possible applications for fuzzy logic control. Japanese manufacturers are in fact now opting for fuzzy controllers even where conventional

controllers would serve just as well. The reasons are that simple fuzzy logic controllers are much easier to design, require fewer electronic components, and are therefore cheaper to produce.

The problem of how to design more complex controllers, however, has only recently met with what appears to be a practical solution. Typically the most difficult part of designing any fuzzy logic controller lies in selecting the fuzzy sets to use for the meanings of the linguistic terms appearing in the inference rules. As the number of rules grows large, the trial-and-error method of selecting the optimal collection of membership functions becomes less feasible. Somewhat of a breakthrough on this problem appears to have been achieved by Akira Maeda at Hitachi's System Development Laboratory. Maeda's idea is to use a form of neural net with back propagation to learn the needed membership functions from a set of training examples. As a test case, Maeda and his coworkers applied this technique to the development of a controller that had been designed previously by trial-and-error. Using this technique, they were able to accomplish in 1 month what had formerly taken 6 months.

A common opinion among Japanese researchers is that most of the important theoretical work in fuzzy control has now been completed and that the next step is up to the commercial manufacturers, i.e., to start churning out applications. This is reflected, for instance, in the fact that fuzzy logic control was one of the three major areas of focus in the original program at the Laboratory for International Fuzzy Engineering Research (LIFE), whereas 3 years later, we find that the subject is barely mentioned within its current program. What is perhaps more correct, however, is that only an initial stage of theoretical development is now more or less complete, and moving to the next stage will require solving an assortment of substantially more difficult problems. Therefore, from a purely pragmatic standpoint, it makes sense to focus on reaping the commercial benefits of what has already been done and to leave for the future the more challenging theoretical issues.

The possibilities for future work, leading to far more sophisticated logic-based controllers, are nonetheless very clear. This will amount to moving from simple one-step rule-based systems to systems employing multi-step reasoning--i.e., rule chaining, together with the necessary truth maintenance systems--which are integrated with other knowledge representation, reasoning, and learning schemes (e.g., semantic nets, frames, conceptual graphs, neural nets, and case-based reasoning). Taking the theory to this next stage will accordingly require progress in a number of important subareas before realizing the more advanced levels of automatic control.

OTHER FUZZY SYSTEMS RESEARCH

As may be seen from the attached bibliography, current fuzzy systems research encompasses a large variety of topics, far too numerous to be covered thoroughly in this short report. Therefore, the following sections will focus rather on the organizations, research institutes, universities, and corporate laboratories with which I became familiar during my visit. Wherever appropriate, this includes a brief survey of the principal researchers and research activities.

The Japan Society for Fuzzy Theory and Research (SOFT)

SOFT was founded and held its first annual meeting in 1984, at which time it had about 20 members. As of 1991, membership amounts to 1,800 individuals and 100 corporations. The current president is Professor Michio Sugeno of the Tokyo Institute of Technology and the vice president is Hideo Tanaka of Osaka Prefecture University.

The society has a few regional chapters, and on 18 May I attended the meeting of the Kansai Branch in Osaka. There I noted from the talks given that the fuzzy systems group in Japan is not completely focused within that area but also overlaps with the broader realms of AI. Two talks were given, one on neural nets by Kazuyoshi Tsutumi of Ryukoku University and one on case-based reasoning by Tetsuo Sawaragi of Kyoto University.

During 12-14 June 1991, I attended and gave a presentation at the seventh annual SOFT symposium, held in Nagoya. Total attendance was 500, of which approximately 100 were from corporations. There were 165 papers presented, covering the entire spectrum of fuzzy systems research, but with a lessor emphasis on theory than on applications. Most Japanese researchers involved in fuzzy systems research are engineers, so that most presentations were in the engineering disciplines. Recognition of the importance of theoretical work was evident, however, by the invitation of Satoko Titani (Chuba University) to give a plenary talk about her work with Gaishi Takeuchi on formalizations of fuzzy logic.

A plenary talk by Masao Mukaidono titled "'Fuzzy' and AI" revealed that the Japanese AI community has followed the lead of its American counterpart in adopting a somewhat hostile attitude toward fuzzy systems research. I was told, however, that the controversy in Japan is not as severe as in the West. Some speculations on why this is the case are taken up in the concluding section of this report.

Laboratory for International Fuzzy Systems Engineering Research (LIFE), Yokohama

LIFE is a 6-year project (1 April 1988 through 31 March 1995) funded by the Japanese Ministry of International

Trade and Industry (MITI) in conjunction with 49 major Japanese corporations. Its stated objectives are (1) to promote research and development (R&D) on applications of fuzzy theory to engineering and (2) to promote domestic and international exchange on the study of fuzzy theory. The managing director is Toshiro Terano, Professor of Control Engineering at Hosei University. Professor Terano is well known as one of the first Japanese researchers in fuzzy systems.

At its inception, LIFE was organized into three "laboratories": (1) Fuzzy Control (especially for production processes and robots), (2) Fuzzy Intellectual Information Processing (decision support systems, image understanding, expert system shells, diagnosis system for power station, language understanding for robots, and evaluation and understanding of numerical information), and (3) Fuzzy Computer (including system architecture, hardware, and software).

In 1990, however, LIFE's goals and research emphasis underwent some fundamental changes, largely because by that time fuzzy technology had found widespread use in industrial and commercial products. Most significantly, it was decided that the subject of fuzzy control had advanced to sufficient maturity that there was no further need for a laboratory on that topic; it was felt that the necessary theoretical work was largely complete and that it was next up to the corporations to start producing applications. As a result, the projects were reorganized into three groups, having three projects each:

1. Decision Support Group: (a) Decision Support System, Project Leader Tano, to develop a fully automated expert system that buys and sells currencies on the international exchange; (b) Plant Operation Support System, Project Leader Yoneda, a system for controlling, monitoring, and diagnosing an electric power plan.; and (c) Process Control Based on Fuzzy Dynamic Models, Project Leader Suzuki, system for control of chemical, fermentation, or environmental processes.

2. Intelligent Robot, all three projects are oriented toward developing a "home helper" robot: (a) Understanding Language Instructions, Project Leader Yokogawa, general problems of natural language understanding and communication; (b) Image Understanding, Project Leader Norita, concerned with color and object recognition and with the interface between images and language; and (c) Planning and Intelligent Control, Project Leader Maeda, concerned with moving-obstacle avoidance and high-level autonomous control.

3. Computer Circumference: (a) Fuzzy Associative Memory, Project Leader Yamaguchi, fuzzy neural networks, integrating fuzzy logic with neural net techniques; (b) Fuzzy Expert Systems, Project Leader Tano, a general-purpose fuzzy expert system shell, which also plays a role in the Decision Support System Project (1a above); and (c) Fuzzy Computer, Project Leader Tokunaga, hardware and software for computers designed specifically for fuzzy information processing.

In addition to promoting industrial applications of fuzzy technology, LIFE also plays an important educational role. The institute houses about 60 researchers, most of whom are younger, junior level employees of major corporations who are pursuing advanced university degrees. In the Japanese university system, a student with a masters degree can obtain a Ph.D. by going to work in the research department of some corporation and producing a series of 8 or 10 publications. The publications then count in place of a doctoral dissertation. Many of the people at LIFE are currently involved in this process. The advantage to the participating companies is that their employees in this manner gain good research experience, together with a solid grounding of knowledge in fuzzy technology, which is then brought back to the corporate research laboratory.

The senior researchers at LIFE are more experienced corporate employees or university professors who visit LIFE on a part-time basis and serve mainly an advisory role. The institute also encourages both short and extended visits by foreigners. Other important functions include organizing national and international conferences and seminars. LIFE has become the de facto hub of activity and communications regarding fuzzy systems research in Japan.

The Science and Technology Agency (STA)

The STA is roughly the equivalent of the U.S. National Science Foundation (NSF), funding primarily university-related research. (STA is also a small contributor to LIFE, but only at 1/20 the amount provided by MITI.) In 1989, STA initiated a program titled "Fuzzy Systems and Their Application to Human and Natural Problems," which began funding fuzzy systems research at the rate of around ¥200 million (or $1.5 million) per year. As such, the actual level of funding provided by STA for fuzzy systems research is much smaller than MITI's contribution to LIFE, but it actually supports a great deal more research activity. This is because STA has no need to provide salaries. Japanese university professors are paid year-round by their institutions and are normally provided at least minimal research facilities. Thus grants from STA cover only funding for

equipment, travel to meetings, business-related entertainment, books, and other incidental expenses.

During the summer of 1991 there were 18 projects being funded under this program, and the word at that time was that the program's budget was soon to be enlarged. The list of project titles is as follows:

(1) Fuzzy Logic

(2) Algorithm of Fuzzy Reasoning

(3) Programming Language and Architecture

(4) Intelligent Control of High-Speed and Unstable Systems (helicopter)

(5) Intelligent Control of Ill-Structured Systems (fermentation plant)

(6) Real-Time Image Understanding (fuzzy-neuro system)

(7) Recognition of Handwritten Letters

(8) Modeling of Sensual Information Processing (image and sensor fusion)

(9) Human Interface in Home Automation

(10) Human Interface for High-Speed and Unstable Machine

(11) Evaluation of Complex Systems (scenario evaluation, fuzzy case-based reasoning)

(12) Fuzzy Information Retrieval

(13) Fuzzy Association (voice recognition)

(14) Evaluation of Reliability of Large-Scale Systems (safety)

(15) Application of Fuzzy Logic to Social and Management Systems

(16) Earthquake Forecasting

(17) Prediction of Air Pollution in Wide Areas

(18) Modeling of Plant Growth

Fuzzy Logic Systems Institute (FLSI), Kyushu Institute of Technology, Iizuka, Kyushu

FLSI was established in March 1990 to conduct experimental research into fuzzy information processing and neuroscience and to promote the wider use of the scientific findings in these domains. The chairman and person primarily responsible for its creation is Professor Takeshi Yamakawa, whose work on fuzzy logic controllers was discussed in a foregoing section.

The initial budget for FLSI was ¥100 million ($750,000) provided by 13 private corporations working in collaboration with the Kyushu Institute of Technology (KIT) and Fukuoka Prefecture. From the prefecture's standpoint, this is part of a long-term effort to establish a new center of technological industry in the Iizuka area, which formerly was a coal mining community and is now economically relatively depressed. The local campus of KIT was itself established for this purpose, and Yamakawa's move there from his former position at Kumamoto University was largely to enable his participation in the formation of FLSI.

New participants have continued to join, most notably Omron Corporation, which as note earlier has traded its support in part for the rights to Yamakawa's patents. At the time of my visit, the institute consisted of three researchers, an administrative director, and two staff assistants, in a small temporary building near KIT. I was given a demonstration there of the inverted pendulum experiment. Construction on a new building, planned to house 40 researchers plus administrative personnel, had been scheduled to begin very soon and was expected to be completed in 1992. The institute also produces the new *Journal of the Fuzzy Logic Systems Institute*, which currently is published only in Japanese.

In addition to Yamakawa's work on the fuzzy inference and defuzzifier chips, he has recently developed a fuzzy neuron chip and demonstrated its utility by means of an application to pattern recognition. A device has been constructed that correctly recognizes handwritten characters with the same degree of accuracy as prior devices, but with much greater speed. The results of these experiments were to be presented at the International Fuzzy Expert Systems (IFES) conference in November 1991.

Other fuzzy systems researchers at KIT are Toyohiko Hirota and Torao Yanaru, together with their student Tomokazu Nakamura. Some of their work concerns the theory of fuzzy inference and its applications in expert systems. In addition, they have been exploring the use of projective geometry to represent various properties of fuzzy systems, a study initiated recently in the United States by Bart Kosko.

Omron Corporation, Fuzzy Technology Business Promotion Center, Kyoto

Omron is primarily a second tier corporation, producing components that other manufacturers use in products for the commercial markets. It also makes equipment for large manufacturers. Omron invested early in fuzzy technology and is now the world's leading innovator in the creation of fuzzy logic devices. A brief chronology follows below. Some of this has been extracted from a 9 May 1991 report by Thomas Hagemann of the German National Research Center for Computer

Science, Tokyo. Additional information has been derived from my own visit. My hosts were Masaki Arao and Satoru Isaka.

In 1966, Omron developed the DECIVAC, an analog computer that implemented a type of probabilistic decision making and was to a certain extent intended to address the same variety of problems as was fuzzy sets. It is interesting that this work almost exactly coincided with Zadeh's first publication in this area.

In 1983, when the first fuzzy technology appeared in Japan (control of a drinking water treatment plant by Fuji Electric and the Sendai Railway project by Hitachi), Takeshi Yamakawa visited Omron's Tokyo office in search of financial support for his fuzzy integrated circuit (IC), a hand-made sample of which he had completed in his laboratory at Kumamoto University in October of that year. Omron saw the potential for this new technology, and in October 1984, Yamakawa came to Omron's head office in Kyoto for a lecture, which was also attended by Kazuma Tateishi, the founder of Omron. He showed a deep interest in fuzzy technology and that year took control of Yamakawa's patent ideas and began developing fuzzy hardware under Yamakawa's supervision. They also at this time began R&D on fuzzy expert systems. By 1986, they had produced fuzzy hardware and a medical diagnosis expert system.

The fuzzy boom in Japan began in 1987. As mentioned earlier, this was the year Yamakawa presented his inverted pendulum at the Second Congress of the International Fuzzy Systems Association. The chips used in that demonstration had been built at Omron. Also during this year, Omron built a "fuzzy computer" [a fuzzy arithmetic logic unit (ALU)]. In 1988 this was marketed as the FZ-1000, and a special task force, the Fuzzy Project Team, was established within Omron. A prototype fuzzy chip designed by Yamakawa was manufactured (now the FZ-5000), and the hybrid (Fuzzy+PID) temperature controller E5AF was developed. Omron took part in establishing LIFE, participated in the Fuzzy Committee of the STA, and received a grant of ¥600 million ($4.5 million) from the Japan Research and Development Corporation (another STA organization).

In 1989, 10 new fuzzy products were announced by Omron, and 60 fuzzy demonstrations appeared at the Omron Festival, an idea contest held regularly within Omron. Professor Zadeh became a senior advisor to Omron, and the Fuzzy Project Team was transformed into the Fuzzy Technology Business Promotion Center, while the team leader was dispatched for 2 years as head of one of the original three research laboratories at LIFE.

By 1990, Omron's total number of patent applications for fuzzy logic devices reached almost 600. These included a fuzzy human body sensor, a fuzzy expert system for machine diagnosis (together with the machinery manufacturer Komatsu), a digital fuzzy chip (the FP-3000), a fuzzy inference board incorporating the digital fuzzy chip (the FB-30AT), and a new tuning method for fuzzy controllers.

As of my visit in July 1991, the total number of patent applications had exceeded 700 and included a camera that can follow moving objects, a robot with sufficient sensitivity to lift cakes of tofu, a color combination recognizer, a bottle cap recognizer, and a temperature controller for a chemical reaction plant. As mentioned earlier, plans were being laid for developing approximately 40 fuzzy logic devices specifically for use in automobiles.

Omron currently employs more that 30 engineers working in fuzzy systems R&D, with applications divided into 5 problem types:

(1) tracking problems (noisy, time-variant systems), e.g., temperature control, tension control, position control, chemical plant control

(2) tuning problems (conflicting constraints), e.g., gain tuning, crane control

(3) human factors (feelings, intuitions), e.g., cruise control, engine diagnostic systems, steering control

(4) interpolation (multi-inputs, multi-level processing), e.g., automotive air conditioner, washing machine, gas/liquid flow regulator, manufacturing device control, label identification

(5) classification (complex pattern recognition), e.g., handwriting recognition

The 31 July issue of the *Daily Yomiuri* newspaper announced an agreement between Omron and NEC "to combine NEC's semiconductor technology with Omron's fuzzy logic expertise to develop fuzzy logic support systems and microprocessors." I was told that Omron expects about 30% of its total business (¥350 billion, or $2.5 billion, in sales per year) to be fuzzy related by 1995. Other manufacturers are, of course, also quickly moving into this area, and Oki Electric Industry Company has recently announced a competing fuzzy inference chip.

Matsushita Electric Industrial (MEI) Company, Central Research Laboratories, Osaka

Matsushita, also known as National/Panasonic, is one of the world's leading producers of consumer products employing fuzzy technology. Others include Fuji Electric, Fuji Film, Hitachi, Mitsubishi Electric, Nissan Auto, Sharp, and Toshiba. Through their advertising,

these companies have successfully equated "fuzzy" and "neuro-fuzzy" with "high technology" in the minds of the Japanese consumers, and one now finds a multitude of products available bearing these labels. For example, while in Tokyo's Akihabara district--the veritable consumer-electronics capital of the world--I noticed one store that had "fuzzy" and "fuzzy-neuro" washing machines from Hitachi, Toshiba, and Sharp. Other products using fuzzy technology were mentioned in a previous section.

My hosts at MEI were Noboru Wakami, Manager, Central Research Laboratories; Yoshiro Fujiwara, Director, Intelligent Electronics Laboratory; and Hideyuki Takagi, Senior Researcher, Central Research Laboratories; together with several other researchers. At the early part of the visit, I was taken on a tour of MEI's Hall of Science and Technology, where I saw displays of its latest products. Those noted as employing fuzzy technology were the fuzzy washing machine and the Palmcorder video camera, discussed earlier.

The Palmcorder is the first video camera to offer an image-stabilization capability within the consumer price range. It uses a small microprocessor to periodically compare the current video image with a prior one, and by means of fuzzy inference rules adjusts the position of the current image in response to the amount by which the two images differ along certain key (fuzzy) parameters. Matsushita also developed the first commercially available air conditioner (cooler and heater) to use fuzzy logic. And a combination of fuzzy rule-based reasoning and neural nets is used for setting the tension in the drives for its video tape recorders.

At the laboratory, I was given a demonstration of recent experiments with an inverted pendulum controlled by a neural net. This shows that neural nets can in some respects replace a fuzzy ruled-based controller. There also has been a concerted effort toward integrating fuzzy rule-based systems with neural nets, largely due to the influence of Takagi. There are various ways in which these two reasoning paradigms may be intertwined. One is to use a neural net approach to "tuning" the membership functions for a fuzzy controller. As mentioned earlier, similar work has been carried out by Hitachi. One demonstration of a system using this approach involved tracking and hitting a moving target. Another was what has been called the Cerebellar Model Arithmetic Computer (CMAC), which uses neural nets to extract fuzzy inference rules from databases. A third was the use of neural nets to provide exact definitions of the fuzzy-logical connectives in an information retrieval system. A fourth used fuzzy reasoning to speed up the learning process in conventional neural nets. A fifth was to implement a set of fuzzy rules as a type of neural net wherein the relation between a rule's premises and conclusion is expressed by a connection between neural net units. (It is perhaps worth mentioning that similar work is currently in progress at Florida State University, this author's home institution).

Another project underway at MEI concerns a multi-step fuzzy reasoning shell. This amounts to an effort to create a fuzzy logic controller with a more sophisticated reasoning component of the kind discussed above. The work is being undertaken in consultation with Professor Motohide Umano of Osaka University and is still fairly much in the idea stage.

Matsushita is clearly investing for the long term in fuzzy technology, to the extent of training personnel specifically for R&D in this area. Hideyuki Takagi in particular has been sent for a year to study at Professor Zadeh's new institute at UC Berkeley. Matsushita also has contributed both funding and personnel at LIFE.

Hitachi Corporation, Systems Development Laboratory, Kawasaki

My hosts at Hitachi were Singi Domen, General Manager; Motohisa Funabashi, Chief Researcher; Seiji Yasunobu, Senior Researcher; and Akira Maeda, Researcher. I was shown three presentations. The first was a "self-tuning algorithm for fuzzy membership functions using computational flow network," which was mentioned in the foregoing section on fuzzy controllers, i.e., the technique developed by Maeda for defining the membership functions of the terms appearing in the inference rules of a fuzzy logic controller. The algorithm is claimed to work efficiently for systems with up to several thousand fuzzy rules.

The second presentation was of Hitachi's expert system shell, ES/KERNEL, which has now sold over 2,000 copies. This incorporates fuzzy logic into a reasoning system that employs frames, rules, and meta rules. The system offers a very convenient graphics interface for defining membership functions and for specifying the fuzzy frames and rules. Many expert systems built with this shell are currently in use, and work toward expanding the shell's reasoning capabilities is ongoing. The Plant Operating System project at LIFE, in fact, is being directed by an employee of this laboratory.

Third were video presentations by Seiji Yasunobu of the two projects for which he is most well known: the famous Sendai Railway and an automated crane. Both of these employ the fuzzy control methods discussed above.

As with Matsushita, Hitachi has numerous "neuro-fuzzy" products available on the consumer market and is investing for the long term in fuzzy technology. Hitachi also is a major contributor to LIFE. Minoru Yoneda, the director of LIFE's Plant Operating System project, is currently on leave

from this laboratory. Hitachi's other interests include industrial applications of fuzzy reasoning and financial applications for supercomputers.

Kansai University, Department of Industrial Engineering, Osaka

From 10 May through 9 July I held a position as Visiting Researcher at Kansai University. My hosts were Yoshinori Ezawa, Associate Professor; Ikuo Itoh, Chairman of the Department of Industrial Engineering; Sanji Nishimura, Dean of the Faculty of Engineering; and Akio Ohnishi, University President. Everyone I met was most hospitable. Professor Ezawa personally accompanied me to most of the places I visited in the Osaka-Kyoto area and was exceedingly helpful in making many introductions. He is to be thanked especially for his kindness.

Kansai University is a private institution where the faculty have fairly heavy teaching loads, in spite of which many are also productive in research. My friend Ezawa is one of those. His work crosses a number of different topics, partly through an ongoing collaboration with Motohide Umano of Osaka University. His current interests include a new, computationally simpler method of representing fuzzy linguistic hedges (e.g., very, rather, extremely) and fuzzy relational databases. His prior work also concerned linguistic hedges, as well as the general problem of fuzzy inference. This stemmed from his work as a doctoral student under Masaharu Mizumoto (currently at Osaka Electro-Communications University).

Others at Kansai University who are working in fuzzy systems and closely related topics are as follows. Takafumi Fujisawa works on image processing by means of fuzzy feature extraction. Toshihiro Fujii, Noriaki Muranaka, and Shigeru Imanishi have developed simulations of fuzzy min max circuits and have also experimented with stabilization of an inverted pendulum. Noriaki Muranaka and Shigeru Imanishi have worked on ternary logic circuits.

Osaka University, Osaka

There are several people at Osaka University working in fuzzy systems. My contact there was Motohide Umano, who I have known personally for several years and who I met with in Japan at Kansai University. In addition to the work discussed above, Umano has studied fuzzy production systems, an implementation of fuzzy reasoning in Lisp, a form of fuzzy Prolog, and an expert system for damage assessment of reinforced concrete bridges.

Another interesting project I became aware of at Osaka University was in the Department of Naval Architecture and Ocean Engineering. This was a proposal by Kazuhiko Hasegawa and Hiroshi Yamakawa to use a fuzzy logic controller to reduce seasickness on large ships. The idea is to mount the ship's deck on hydraulic lifters, fastened into the hull, which would then move the deck in compensation for the roll of the sea. This same idea could conceivably also be used to stabilize gun turrets and missile launchers on battleships.

Also of interest is Toshiomi Yoshida's use of fuzzy pattern recognition in the control of fermentation processes. This is being carried out in collaboration with Konstantin Konstantinov of Japan's International Center of Cooperative Research in Biotechnology.

Kobe University, School of Engineering, Kobe

My contact at Kobe University was Hiroshi Kawamura in the Department of Architecture, who I met on 18 May at the meeting of the Kansai Branch of SOFT. Kawamura's work has concerned the use of fuzzy logic in two different problems related to earthquakes. (1) the prediction of earthquake ground motions and structural responses and (2) the control of motion in civil engineering structures. Some of this work has been done in collaboration with James Yao of Texas A&M University.

Others working at Kobe University are: Shinzo Kitamura, stability analysis of fuzzy logic controllers; Ayaho Miyamoto, fuzzy expert systems for safety evaluation, maintenance, and rehabilitation of concrete bridges; Keizo Nagaoka, measurement of student response time in computer-aided instructional systems; and Naoyuki Tamura, fuzzy Prolog based on interval-valued fuzzy sets.

Kyoto University, Department of Precision Mechanics, Kyoto

At Kyoto University I met with Tetsuo Sawaragi and Osamu Katai. Professor Katai is head of a small laboratory, which includes Sawaragi as well as Sawaragi's former doctoral advisor, Sosuke Iwai.

Most of the activities at Katai's laboratory are directed toward the more general issues surrounding knowledge-based reasoning systems, and fuzzy logic is viewed as a tool for addressing some of the associated problems. One project has used a fuzzy logic controller in conjunction with standard AI techniques for robot obstacle avoidance and motion planning. In addition, Katai and Iwai have studied representations of belief and plausibility in conjunction with problems of nonmonotonic reasoning.

Other projects have grown out of Sawaragi's doctoral studies in intelligent decision support systems. That work is akin to earlier work in "structural modeling" of complex societal systems, wherein the causal interrelations between the system's variables are displayed in a directed graph, e.g., Movement of Business Into Cities --> Increased Business Use of Automobiles and Truck --> Increased Traffic Problems --> Movement of Businesses

Back Out of Cities. In Sawaragi's thesis such diagrams are called "cognitive maps." More recent work has developed much more complicated types of events (problem, request, enablement, revenge, etc.) suitable for modeling international political-economic systems. These use fuzzy linguistic terms for characterizing properties of such events and ha e entailed developing new methods for extracting fuzzy sets from raw data.

Osaka Prefecture University, Department of Industrial Engineering, Osaka

My hosts at Osaka Prefecture University were Professor Hideo Tanaka together with several members of his laboratory and one of his former doctoral students. Professor Tanaka's primary research topic has been fuzzy (or possibilistic) linear regression analysis, although he has also touched on numerous other topics through collaboration with his coworkers.

Further research activities include the following. Hidetomo Ichihashi has studied the mathematical properties of fuzzy numbers, has investigated the use of neural nets for learning fuzzy set membership functions from small sets of training examples, and has worked with Tanaka on a type of fuzzy inference based on the Dempster-Shafer theory of evidence. Hisao Ishibuchi has developed an approach to fuzzy data analysis by means of neural nets and has worked with Tanaka in the area of fuzzy multi-objective programming. Masahiro Inuiguchi and Yasafumi Kume have also worked in fuzzy mathematical programming. Tanaka's former student, Koji Izumi (now at Hannan University in Nara), works on the formal aspects of fuzzy logic, being concerned with fuzzy quantifiers, representations of linguistic hedges as modal operators, and a kind of fuzzy reasoning based on intuitionistic logic.

Osaka Electro-Communications University, Department of Management Engineering, Osaka

I visited Professor Masaharu Mizumoto, who is well known for his many publications in fuzzy systems. These date from his theoretical work with the late Professor Tanaka (his doctoral advisor) on the algebraic properties of fuzzy numbers, published in 1975. He happens to have been Yoshinori Ezawa's doctoral advisor while at Osaka University.

Mizumoto currently studies fuzzy logic controllers and gave a demonstration of his own version of the inverted pendulum experiment. His approach differs from that of Yamakawa in that he is able to accomplish stabilization with an ordinary 25-MHz personal computer. This is accomplished by precomputing all the possible inference results and then storing them in a table in main memory, for fast look up. The drawback of this approach is that one loses much of the flexibility (robustness) of a system in which the inferences can be computed in real time by specially dedicated chips. Mizumoto's device is useful, though, for experimenting with different rule sets and determining which types of rules give the best results. He tends to believe that the min-max compositional rule of inference (as computed by Yamakawa's chip) is not necessarily the best method. His experiments show good results using product-sum rules.

He also continues to delve into theoretical problems and recently has developed a method of linguistic evidence combination (i.e., conjoining rules whose conclusions all involve terms related to the same general property) involving a kind of linguistic interpolation. This may be useful in both fuzzy controllers and fuzzy expert systems.

Osaka Institute of Technology, School of Industrial Engineering, Osaka

Here my hosts were Kiyoji Asai and Junzo Watada. Professor Asai was among the very first Japanese to study fuzzy sets, having taken an interest in it shortly after Zadeh's first publication on the subject in 1965. He was founding president of SOFT and is well known for his many publications. Professor Asai is now one of the leading figures in the international fuzzy systems community.

Professor Watada also has many contributions to fuzzy systems research and currently serves as president of the Kansai Branch of SOFT. His recent work has concerned diagnostic expert systems using Dempster-Shafer theory.

Meiji University, Faculty of Engineering, Kawasaki

I met with Professor Masao Mukaidono, another well-known member of the international fuzzy community. His research over the past several years has focused primarily on developing a fuzzy Prolog. Most of the work to date has dealt with an appropriate adaptation of linear resolution (the essential component of standard Prolog). This is still in the theoretical stage, although there have been some prototype implementations.

In addition to his work on fuzzy Prolog, Mukaidono has investigated the properties of fuzzy interval logic, presumably because it is computationally simpler than full-fledged fuzzy logic. Interval logic may eventually become the basis for an alternative form of fuzzy Prolog. He has also studied the use of neural nets for learning fuzzy inference rules and has done rather extensive work on the subject of fuzzy switching functions.

Hosei University, Department of Instrument and Control Engineering, Tokyo

At Hosei University I met with Kaoru Hirota and saw video demonstrations of robots developed in his laboratory. One of these is a general-purpose robot that is now being manufactured by Mitsubishi. The first video showed an early version of this robot, presented at IFSA-87, playing two-dimensional ping-pong with a human opponent. The experiment used a video camera to track the location of the ball and a collection of 30 inference rules to determine the hitting position. The movement of the robot was very slow and deliberate but nonetheless surprisingly accurate considering that it was being controlled by a 16-bit, 5-MHz NEC personal computer. A second demonstration of the robot showed it doing a moderately good job of traditional Japanese flower arrangement, using a collection of between 30 and 50 rules. Third was a tape of the robot playing yo-yo. Here a video camera watched the movement of the yo-yo against a white background, and the robot moved accordingly.

A final video showed a more recent experiment, involving a fuzzy logic controlled robot that throws darts at a falling object. The more dramatic segment showed the robot throwing at an object falling through an array of pegs, like in a pinball machine, and scoring a hit on virtually every try. There also have been some attempts to program a robot to grasp a spherical object moving erratically in two dimensions. The results here have so far been only marginally satisfying, with the robot missing the object more often than successfully grasping it.

Another interesting project, mentioned earlier, is design of a fuzzy flip-flop circuit. This work shows promise of leading to the first "fuzzy memory" and conceivably can serve as the basis for a general-purpose fuzzy computer In essence, Hirota's fuzzy flip flop is a generalization of the binary logic J-K flip-flop, which is the basis for most conventional digital computers. An important property of Hirota's fuzzy flip-flop is that it embodies the binary flip-flop as a special case. Thus with this device one should be able to program both binary and fuzzy logic on the same machine. There reportedly has been discussion at LIFE about starting a project to advance this idea.

Tokyo Institute of Technology (TIT), Departments of Intelligence Science and Systems Science, Yokohama

At TIT I met with Shigenobu Kobayashi in the Department of Intelligence Science and Anca Ralescu in the Department of Systems Science. The latter is also the home department of Michio Sugeno, whom I had met on 5 August at LIFE.

Because Kobayashi's work is almost exclusively concerned with case-based reasoning, it will be discussed in the section below. Professor Ralescu is an American, who was on a visiting appointment in Sugeno's laboratory, and starting in mid-August she will be visiting at LIFE for a year under a grant from the U.S. NSF. One of her interests is a model of fuzzy reasoning based on possibility and necessity measures. She has also studied the use of neural nets for learning fuzzy set membership functions.

Of special interest is Sugeno's current work, mentioned previously, on a voice-controlled helicopter. The objective is to build a helicopter that can be flown by simple voice commands, such as "hover," "forward," "back," "left," "right," "up," "down," and "land." One potential application would be an unmanned helicopter used for sea rescue, controlled by voice commands from a mothership.

At the time of our meeting, Sugeno had already successfully automated all the necessary basic functions for a 1-meter model helicopter, as well as the hovering function for a 3-meter model. In both models, each function is automated by means of a fuzzy logic controller composed of a relatively small set of inference rules. For example, hovering requires 36 rules, broken down into one group of 18 main rules (to stabilize position and speed) and one group of 18 subrules (to stabilize attitude), where each of these is further decomposed into simpler groups of 2 to 6 rules. Ordinary flight control requires another 30 rules, 14 for speed and 16 for attitude, and rotation requires 28 rules, 14 for speed and bank angle and 14 for attitude. In total 15 input variables need to be monitored. Nine of these are the current value, rate of change, and acceleration of pitch, roll, and yaw. Others include altitude and various speeds. Outputs are instructions to the helicopter's usual controls, i.e., stick, pedals, etc.

In reviewing the outline for Sugeno's controller, one cannot help but be struck by its relative simplicity. Although there are in total more than 100 rules, each lowest-level rule group is logically independent of all the others and can be treated conceptually as a self-contained unit. Thus overall design and tuning should be fairly easy. Real-time tests of the 1-meter model showed that the fuzzy logic controller actually does better than a trained human, i.e., it reaches stability in the hovering operation more quickly. It also did very well on the other functions. Given successful completion of tests with the 3-meter model, they will next seek funding to work on a full-size helicopter.

Tokyo Electro-Communications University, Department of Communication Systems, Tokyo

My last visit was with Nakaji Honda, where I learned of a project to control the lighting of a room by means of a hierarchically organized rule-based fuzzy

controller. The aim is to produce either uniform brightness or special effects in certain parts of the room, so as to provide a physiologically and psychologically comfortable atmosphere. The problem is complicated by requiring that the system be able to control interior lighting in such a way that it supplements and/or cooperates with external natural light, which is constantly changing. While this research focuses on an application of seemingly limited utility, it apparently is directed toward a much larger and important application, namely, to automate the control of large power distribution systems in response to changing loads.

Hiroshima Institute of Technology, Faculty of Engineering

From the May 1991 issue of the *Journal of the Japan Society for Fuzzy Theory and Systems*, I learned of some recent work by Kazuho Tamano on an optical fuzzy inference system. In this system, graphs of the membership functions for a rule's fuzzy linguistic terms are etched onto transparent plates, a light is passed through the plates, focused by a set of Fresnel convex lenses, and the amount of light coming out is measured by a set of photo diodes. These measurements yield the rule's inferred conclusion, in accordance with Mizumoto's product-sum-gravity method of fuzzy inference. The inference is thus virtually instantaneous, although multiple conclusions still need to be combined by an electronic defuzzifier.

This appears to be the very first report of such an inferencing device. The results are still very much in the experimental stage, but the possibilities are intriguing. Future experiments are planned wherein the etched plates are replaced with programmable light emitting diode (LED) displays.

CASE-BASED REASONING

Case-based reasoning (CBR) is largely the invention of Christopher Riesbeck of Northeastern University and Roger Schank of Yale. The underlying intuition is that much of human reasoning and decision making is derived from remembered personal experiences. The term "cased-based" reflects a focus on areas like medicine and law, where remembered experiences can be represented as individual cases. The basic idea is to develop a database of cases that can be accessed for the purposes of a current problem situation. The given situation is analyzed for its relevant properties, and based on these properties, any similar cases are retrieved from the database and modified or otherwise utilized for the present purposes. This produces a new case that is then added to the database for future reference. The CBR paradigm is in this manner also a learning paradigm, building its knowledge base through ongoing interactions with the user. This feature is attractive, as it offers a way to get beyond the knowledge acquisition bottleneck inherent in most other AI paradigms.

An early investigation of the methods for implementing such a system was carried out by Schank's doctoral student, Kristian Hammond, where the cases were recipes for Chinese cooking. Hammond's CHEF served as a vehicle for exploring the possibility of fully automating all the phases of case-based reasoning, i.e., case retrieval, modification, storage, and repair. CBR has subsequently attracted a sizable following in the West, and for each of the last 3 years there has been a workshop on the subject sponsored by the Defense Advanced Research Projects Agency (DARPA).

During my stay in Japan, I uncovered only two places where there is any significant activity in CBR. The main one is Shigenobu Kobayashi's laboratory at the Tokyo Institute of Technology. Kobayashi is well known for his prior work in AI, having written rather extensively on the subject of machine learning. His work has explored the possible theoretical connections between explanation-based learning and CBR, and he and his coworkers had undertaken applications in three areas: (1) an expert system for configuring a cigarette rolling machine, (2) production process diagnosis, and (3) information retrieval. The work on (1) features an "interactive" CBR system, which foregoes the attempt at full automation and provides that the user play a role in each phase of the CBR process. This is reasonable, as one should not expect to be able to fully automate CBR for problems much more complex than simple cooking recipes.

The other focus of activity in CBR is Osamu Katai's laboratory at Kyoto University. Here the main proponent appears to be Tetsuo Sawaragi, working in collaboration with Katai and Sosuke Iwai. Projects in this area are currently only in the planning stages, with proposed application domains similar to those undertaken by Kobayashi, particularly diagnosis and information retrieval.

From my meeting with Seiji Yasunobu at Hitachi, I learned that there have been recent discussions at his laboratory about studying CBR, but that it was not clear to them how or where these principles could be applied. Having just learned that Hitachi is beginning a program to develop and market a package of software development tools, I suggested the possibility of using CBR in software engineering, for both software system design and software development project planning. In the former, cases are former designs, and in the latter, cases are plans for implementing those designs. His initial reaction was that this seemed like a reasonable idea. It is likely that Japanese involvement in CBR will continue to grow.

CONCLUDING REMARKS

From a very early age, Japanese school children are frequently reminded of their country's vulnerable economic condition. They live in an island nation, with a population equal to a third of the United States crowded onto a land mass slightly larger than California, and of which almost three-fourths is mountainous and essentially uninhabitable. They have no natural resources and not enough space to grow their own food. They have been grappling with the related problems for several generations.

Their involvement in the Second World War was largely an act of desperation, to increase their space by acquiring part of China. When that failed they determined that their only option was to succeed in the international market place, earning enough money to buy what they need to survive. Their strategy since that time has been to import raw materials and turn them into products that can be sold abroad.

In order to accomplish this it has been necessary for them to excel in business and technology. They are a people who have no choice but to work hard and live by their wits. In order to accomplish their goals they are accordingly inspired to acquiesce in a rather tightly controlled and conservative society, with a high value placed on social harmony. The Japanese are well aware that they cannot permit excessive squabbling among themselves, for they otherwise cannot live together in such a small space and probably could not collectively survive. This feeling inspires in them a desire to care for, and cooperate with, one another in ways mostly unthinkable in the West. It also allows them to respond rapidly and in unison to meet new challenges.

Against this backdrop we have seen this nation rise rapidly to the forefront in the realm of information technology. With respect to their now taking a leading role in fuzzy systems research, it has been proposed that this is because Japan is one of the Eastern cultures, which are reputed to be more receptive of vagueness and imprecision. My personal opinion is that this is only a small, and perhaps negligible, part of the overall cause. It seems rather that Japan's investment in fuzzy systems is only one of many instances of the same overall strategy. They constantly scour the horizon, watching for new scientific ideas, which in effect are regarded only as other raw materials, items waiting to be transformed into marketable commodities. This approach to technological progress is evident even in their policy toward funding research at large corporations and in universities. The prevailing emphasis has been on applications rather than theory. A nice illustration of this fact is the following breakdown of presentations at the congress of the International Fuzzy Systems Association (IFSA-91) held in Brussels, Belgium, last July. The papers were subdivided into four areas: Artificial Intelligence (AI); Engineering (Engin); Computer, Management, and System Sciences (CM&SS); and Mathematics (Math). Note not only the distribution but the proportion of total participation by Japanese.

Topic	Total Papers	By Japanese	% Japanese
AI	59	23	39
Engin	65	37	57
CM&SS	74	23	31
Math	60	3	5
All	258	86	33.3

The strong emphasis on applications has been orchestrated largely by MITI and STA through their funding policies. In contrast with the United States, MITI can to a certain extent dictate where large corporations will focus their R&D, simply by creating funding opportunities in desired areas while withdrawing funding in others. They are also not afraid to invest occasionally in high-risk ventures.

Just as in the United States, however, the granting agencies do make their decisions on the basis of advice received from their leading scientists. And this points to another possible reason why fuzzy systems have flourished in Japan. Japanese university professors are all paid on a 12-month basis, so that they have no need for summer salaries and are typically provided at least the minimal funding necessary to do their research. Hence, there is not as much incentive as in the United States for faculty to compete for research funds, which means there is less cause to discredit ideas other than one's own. Discussions regarding the pros and cons of a new idea can take place in a much more friendly and collegial manner, simply because one's livelihood and/or academic survival is not so much at stake. When a few Japanese professors took an early interest in fuzzy systems, they were at least treated with respect, if not actively encouraged.

Fuzzy systems research has been suppressed in the United States largely because the leading AI figures, and principal advisors to the granting agencies, come from the traditional background of symbolic approaches to AI. Accordingly, the models of semantic inference proposed by Zadeh seemed not only strange but also threatening. Out of this came an apparent (although unstated) policy to provide only minimal funding in this area. Also, because U.S. academics do not value social harmony and mutual respect as much as do the Japanese, there was great sport made in some circles of ridiculing and alienating anyone who was identified with the fuzzy systems movement. This only exacerbated the problem of gaining support.

As to what might have been done, or what could be done in the future, to prevent similar phenomena from occurring, I can only offer a few tentative suggestions. There is, of course, little that can be done about the lack of importance placed on values like social harmony and mutual respect, but then this may not be altogether necessary. Out of rugged individualism and competitive self-promotion comes also a wealth of both scientific, philosophic, and artistic creativity. Indeed it is still the case that the deep theoretical breakthroughs are being accomplished in the West. This is because we continue to support the intellectual infrastructure necessary for this to occur. What is needed, therefore, is really only a better system for (1) protecting and encouraging fledgling ideas and (2) transforming theory into applications.

For the former I would propose a partial reorganization of the NSF, creating a branch organized somewhat along the lines of the Office of Naval Research (ONR). Specifically this would amount to setting up directorships in major funding areas wherein the directors themselves have the authority to be proactive, i.e., to formulate and exercise their own vision as to what research should be supported. Within this context, there should also be special funding set aside for high-risk ventures, with the understanding that the director is not to be penalized if a particular project fails to bear fruit. The performance of the director would be judged not only by his superiors but also by feedback actively solicited from the sector of academia in concern. Also as in ONR, NSF directorships should have indefinite duration, thereby allowing directors to lay plans and carry them out, and it should be possible for researchers to establish a relationship with the agency, based on past performance, rather than having to start anew every couple of years. It would also help to increase the overall budgets of these agencies; there are too many scientists whose talents are being wasted.

The latter aim constitutes a much more difficult issue, as the United States has strict rules regarding government involvement in private enterprise. It would seem, though, that some agency such as MITI could be established to aid corporations in identifying potentially fruitful lines of R&D and to grant incentives for working in those areas. Whether projects such as LIFE are truly worthwhile has yet to be established, but more programs that promote collaboration between universities, government, and industry would certainly be in order. American ingenuity should be able to provide the needed new bridge between theory and applications.

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MATHEMATICAL THEORY OF NETWORKS AND SYSTEMS '91 (MTNS '91)

The Mathematical Theory of Networks and Systems '91 conference and site visits in Japan, Hong Kong, Macao, Singapore, and India are summarized.

by Biswa N. Datta

GENERAL OVERVIEW OF THE CONFERENCE

The international symposium on the Mathematical Theory of Networks and Systems (MTNS '91) was held in Kobe, Japan, from 17 through 21 June 1991. This was the ninth MTNS meeting and the first to be held in the Far East. The previous meetings were held in the United States, Canada, The Netherlands, Sweden, and Israel. MTNS meetings have been organized biannually since 1973. MTNS '91 was held at the International Conference Center on the manmade port island in Kobe City. Kobe is the largest port city in Japan and one of the most popular tourist spots, surrounded by centuries-old historical cities like Kyoto, Osaka, Nara, and Nagoya.

The local organizing committee of the meeting, co-chaired by Profs. H. Kimura and S. Kodama, both of Osaka University and internationally renowned control theorists, did a super job. One of the remarkable skills of the organizing committee was to attract sponsorship support from most of the leading corporations of Japan, about 50 of them. I have attended several of the past MTNS conferences, but this was the only conference with so many corporate sponsorships. The sponsorships by such a large number of corporations clearly indicate the strong industry university relationship that exists in Japan. I wish that a similar relationship existed in the United States as well.

The conference was truly international in nature. There were 558 attendees and they came from all over the world: Australia, Belgium, Brazil, Canada, France, Hong Kong, India, Israel, Italy, Japan, Korea, Malaysia, Mexico, The Netherlands, Poland, China, Taiwan, Spain, Sweden, Switzerland, Turkey, the United Kingdom, the United States, Vietnam, and Yugoslavia.

The purpose of the conference was to bring together research engineers, mathematicians, and computer scientists to discuss mathematical problems of systems theoretical in nature arising in applications of current interest. It is a fact of life that engineers and mathematical scientists hardly communicate with each other. On the other hand, many research projects in applied science and engineering are heavily dependent upon successful interdisciplinary collaborations of mathematicians, engineers, and computer scientists.

The scientific program of the conference consisted of plenary lectures, special topic lectures, mini course, invited and contributed sessions, and a poster session.

PLENARY LECTURES

The goal of the plenary lectures was to provide the participants with the major research developments in topics in the areas of interest to the conference. All these lectures had some tutorial flavor.

In his opening address, Prof. Katsuhisa Furuta, a well-known control theorist from the Tokyo Institute of Technology, discussed how intelligent control can be effectively used in robotics. Intelligent control is usually defined as the "activities in the intersection of automatic control and artificial intelligence"; however, Furuta coined a new definition of intelligent control. He defined intelligence as "the ability to adapt to the environment" and intelligent control as "the control to provide the intelligence to the system." Based on this definition, he proposed a mechanism that appears to be effective for "sensor based robot control such as compliance control [and] vision based servo and coordination control of multiple arms".

In another plenary talk on a similar topic titled "Systems Theory and Intelligence," Dr. M. Vidyasagar, the director of the Center for Artificial Intelligence and Robotics in Bangalore, India, showed that there are several areas of intelligence which give rise to interesting and challenging problems in systems theory. By "intelligence" Dr. Vidyasagar referred to those aspects of (rational) human behavior that computers find difficult to replicate, and by "systems theory" he referred to a wide variety of topics such as complexity theory, stochastic algorithms, simulated

annealing, neural networks, etc., besides the traditional areas of control theory.

The other plenary lectures were given by Profs. B.D.O. Anderson of the Australian National University; Israel Gohberg of Tel Aviv University, Israel; and A. Isidori of the University of Roma, Italy.

Anderson's plenary talk was on optimizing the discretization of continuous time controllers. A standard problem in digital control is replacing a continuous time controller with a discrete time controller so that, as far as possible, closed-loop properties are preserved. The standard approaches to solve the problem do not make any use at all of the plant, whereas the closed-loop properties clearly depend on the plant as well as the controller. Anderson proposed some novel approaches for solving the problem that make use of the knowledge of the plant. Two aspects of the closed-loop properties, stability and the closed-loop transfer matrix, are emphasized.

Gohberg's talk was on the interplay between interpolation problems and systems theory. He described some recent developments in interpolation theory and showed how these developments have greatly influenced modern theoretical systems theory research.

Isidori's talk was on robust regulation of nonlinear systems. Research in nonlinear systems is still in its infancy. Isidori showed how certain problems in nonlinear systems can be solved using linearization techniques while for others these techniques are not useful.

SPECIAL TOPICS LECTURES

The goal of the special topics lectures was to present research advances in certain selected areas of interest to the conference, the lectures were really designed for specialized subgroups of the participants.

The special topics lectures were as follows:

- F.M. Callier, Univ. Notre-Dame de la Paix, Belgium, "Recent Advances on Spectral Factorization and LQ-Optimal Regulation for Multivariable Systems"
- Bruce Francis, Univ. of Toronto, Canada, "Sampled-Data Control Theory"
- M. Halsler, Ecole Polytechnic, Switzerland, "Topological Methods for the Qualitative Analysis of Nonlinear Circuits"
- Pramod Khargonekar, Univ. of Michigan, "State-Space H_∞ and Robust Control Theory"
- M. Ikeda, Kobe Univ., Japan, "Decentralized Control of Large-Scale Systems"
- Pradip Pandey, UC Berkeley, "Solving the Algebraic Riccati Equations on a Supercomputer"
- A. Morse, Yale Univ., "A Conceptual Framework for Parameter Adaptive Control"
- K. Murota, Tokyo Univ., "Combinatorial Systems Theory"
- A. Ohsumi, Kyoto Institute of Technology, "Derivation of the Schrodinger Equations from Stochastic Control"
- M. Silva, Spain, "Linear Algebraic Techniques for the Analysis and Synthesis of Petrinets"

Two of the lectures that I found extremely interesting are described below.

The talk by Prof. K. Murota of Tokyo University was on combinatorial systems theory. Murota showed how certain basic concepts such as controllability, observability, stabilizability, etc. that arise in the design and analysis of linear control systems in state-space modeling can be studied eloquently using the techniques of combinatorics. These discussions were strongly inspired by the earlier work of C.T. Lin on structural controllability. The far-reaching goal is to develop a combinatorial analogue of dynamical systems theory in a matroid theoretic framework.

Prof. M. Silva's talk was on how tools from linear algebra could be used in the analysis and synthesis of Petrinets.

MINI COURSES

There were two mini courses: one on recent advances in neural network theory given by S. Amari of the University of Tokyo and M.I. Jordan of the Massachusetts Institute of Technology and the other on $H_\infty/H_2/\mu$ synthesis given by John Doyle of Caltech, K. Glover of Cambridge University, U.K., and Andy Packard of UC Berkeley. The goal of these courses was to educate the participants in the selected research areas. The presentations were tutorial in nature, with particular attention given to motivation, definitions, and examples.

SCIENTIFIC COMPUTING AND CONTROL THEORY

Activities in MTNS '91

The design and analysis of linear control systems give rise to a variety of interesting computational linear algebra problems. Some of the well-known ones are: controllability and observability problems, stability and inertia problems, feedback stabilization and eigenvalue assignment problems (the so- called pole assignment problems), frequency response problems, and matrix equation problems (such as Lyapanov, Sylvester, Riccati). Because of the importance of these problems, they have been very well studied both in mathematics and control literature. There

exists a oluminous work, both on the‾ , and computation of these problems. Theory is extremely rich; however, one cannot say the same thing about computation. Many of the methods available in present control theory textbooks are not suitable for computer implementations. Most of these methods, in fact, were developed before the computer era and are not based on computationally sound techniques. Fortunately, the situation is changing very fast. In the last few years, computationally viable methods have been developed for several of the above problems, and presently studies are being conducted not only on the development of computationally viable methods but also on other important numerical analysis aspects, such as perturbation analyses of the problems, stability analysis of the algorithms by backward and forward round-off error analyses, etc. Unfortunately, most of those algorithms, however, are not satiable for large and sparse problems. They are based on transformation of the system matrices to some sort of condensed forms such as Hessenberg, triangular, Real-Schur form, etc., and the methods used to achieve these forms, such as Gaussian elimination, Householder and Givens methods, the QR iterations, etc., are well known to give fill-in. On the other hand, there are practical situations such as the design of large space structures (Ref 1 and 2), control of power systems (Ref 3), etc. that give rise to very large problems and, like most practical large problems, these problems are sparse and well structured, too. Most of the existing methods are not designed to take advantage of the structures exhibited by these problems.

Another aspect of control theory research that needs the attention of computational scientists and practicing engineers is parallel computations in control. Nowadays, when there is a revolution going on in the area of parallel/vector computations, any serious research in applied sciences and engineering should pay attention to this aspect or research. Unfortunately, control theory is lagging behind with respect to other areas of science and engineering. For example, in recent years, much effort has been devoted to parallelizing sequential algorithms and developing new parallel algorithms in numerical linear algebra [for an account of the recent developments in the area of parallel matrix computations, see the excellent survey by Gallivan et al. (Ref 4)]. Parallel software libraries based on these algorithms are being developed on some of the existing parallel machines. It is only natural to take advantage of those parallel linear algebra algorithms and the associated software libraries and software packages suitable for hierarchial computations (such as the recent linear algebra package LAPACK) to develop parallel algorithms for linear control problems. One obvious advantage of doing that is programming effort will be greatly reduced. Anyone who has experienced parallel programming and computations will admit how hard it is to code and debug some of the new parallel/vector computers. Admittedly, some of the linear control algorithms (e.g., eigenvalue assignment methods via implicit QR iterations) are very sequential in nature. For these problems novel parallel algorithms (parallel algorithms that will perhaps never be used on sequential machines) need to be developed.

In control theory, there are opportunities for the development of both types of algorithms. Activities in the area in control theory of large-scale and parallel computations, unfortunately, are very limited. Only a handful of papers have appeared so far (see the references quoted in Reference 5). A recent panel report (Ref 6) on "Future Directions in Control Theory" has emphasized, among many other things, the need for expanded research in these areas. Indeed, research on computational methods in control theory is still in its infancy.

To address the need for research in these areas, I organized an invited special session on numerical linear algebra in signals, systems, and control for this conference. In my talk titled "Parallel Computations in Control Theory," I first summarized the state-of-the-art research in this area and then described in detail parallel algorithms for eigenvalue assignment and observer matrix equation problems along with implementational details of these algorithms both on shared memory and distributed memory machines. I showed some actual results of implementations on a Cray X-MP/4, Cray Y-MP, Alliant FX/8, and transputers. Prof. R. Plemmons spoke on parallel algorithms for linear prediction on inverse factorization.

Daniel Pierce of Boeing Computer Services spoke on sparse matrix techniques for condition estimation based on a rank-revealing QR factorization. Attempts are being made by researchers such as myself and others to incorporate these powerful tools from sparse matrix computations into developing algorithms and analyzing robustness properties for feedback stabilization associated with large second order models.

The final talk of the session was delivered by George Cybenko on linear algebra aspects of Wavelet transforms.

Another invited session on parallel algorithm design was organized by L. Thiere of Univ. Saarlandes, Germany. The talks were given by A-A. Sayed of Stanford University on "Fast Algorithms for Generalized Displacement Structures," based on joint work with Tom Kailalh; by P. Dewilde on "The Algebra of Parallel Processors"; by L. Thiere on "Multidimensional Discrete Event Systems and Their Applications to Parallel Program Design," based on joint work with W. Backes and

U. Scwniegelshohn of the IBM T.J. Watson Research Center; and by J. Bu on "Design of Fixed-Size Systolic Arrays: Control Structure and Data," based on joint work with Ed T. DePrettere of Delft University Tech. Finally, as mentioned earlier, a special lecture on supercomputer solution of the algebraic Riccati equation was given by Pradip Pandey based on joint work with Alan Laub of UC Santa Barbara.

Finally, let me mention another talk by Prof. Brian Anderson on the finite word length (FWL) design of state-space digital systems with weighted sensitivity minimization and spareness consideration, given at an invited special session on Finite Precision and Quantization Effects in Control Design II organized by Profs. E.I. Verriest of the Georgia Institute of Technology and M. Gevers of Louvain University of Belgium. Anderson's talk centered around the optimal FWL state-space design, which aims to identify those realizations that minimize the degradation of the system performance due to the FWL effects.

Remarks

As expected, activities in the area of computational methods for control systems design and signal processing were far less than the other areas. I would like to see more special sessions, more contributed talks, and even plenary lectures in this area in future MTNS meetings.

LINEAR ALGEBRA AND CONTROL AND SYSTEMS THEORY

Linear algebra and control and systems theory have long enjoyed a natural synergism; however, the interdisciplinary activities blending these two areas were disappointingly fewer than expected. Fortunately, a significant increase in activities in this area has taken place since the .‾84 American Mathematical Society (AMS) summer research conference on Linear Algebra and its Role in Systems Theory and the two interdisciplinary SIAM conferences on Linear Algebra in Signals, Systems, and Control, 1986 and 1990 (Ref 7 and 8), chaired and organized by the author. For example, for the current MTNS, there were noticeable activities in this area. There were several invited sessions. One was organized by A.C. Ran of Virje University, The Netherlands, on Matrix Equations and Applications. Two sessions on Matrix Completion and Extension Problems were organized by L. Rodman of the College of William and Mary. Several linear algebraists and system theorists, such as Leiba Rodman, A. Ran, M.A. Kaashoek, Carlos De-Sonza, etc., gave talks in these sessions. There was also a very nice session on Interpolation Problems for Matrix Functions and Applications in Systems Theory organized by M.A. Kaashoek of Virje University, The Netherlands. In addition to Kaashoek, the participants included A.C. Antoulas, Joe Ball, Leiba Rodman, and A. Tannenbaum. Profs. Kaashoek, Ball, Rodman, and Tannenbaum are leading authorities in operator theory and their work heavily involves applications of operator theory to systems theory and H_∞ control. Prof. Antoulas is well known for his work on interpolation and its applications.

H_∞ AND ROBUST CONTROL

One of the central areas of research in present-day control theory is H_∞ control. Suppose that ΔP is an unknown perturbation to a nominal plant P and that the feedback is internally stable for $\Delta P = 0$. A very important question then is how large can $|\Delta P|$ be so that the internal stability is maintained? The question can be answered in terms of the H_∞-norm on a weighted closed-loop transfer function. The goal is to design a feedback controller so that the closed-loop system is internally stable and the H_∞-norm of the transfer function matrix is minimized.

Dr. Vidyasagar, in his plenary talk, remarked jokingly, "This conference has been hijacked by H_∞ people." I think that there was some truth in the statement. The number of talks in this area in any category was far greater than any other area addressed by the conference. One of the reasons for this was, of course, love for H_∞ control by Japanese control theorists who were involved in organization. In fact, I was told by Prof. Kimura and his colleagues that H_∞ control techniques are not academic anymore; they are being incorporated in industrial applications such as in the design of large space structures. I am aware of similar activities at the Langley NASA Research Center in our country; however, the Japanese seem to be ahead.

CONCLUSIONS

All indications are that the conference was a great success; the aim of the conference, to bring together mathematicians and control and systems theorists, was somehow achieved. I, however, expected somewhat more participants from industries, especially since the conference had such a large number of corporate sponsorships.

As mentioned before, I strongly believe that the mutual interactions and research collaborations between mathematicians, computer scientists, and practicing engineers are important ingredients in timely success of any interdisciplinary project.

SITE VISITS IN JAPAN

Tokyo Denki University (TDU)

At TDU my hosts were Prof. Hiroshi Inaba of the Department of Information Sciences and Prof. T. Kamabayashi of the Department of Mathematics. Inaba is a well-known control theorist

in Japan and the group leader of a research group working mainly on infinite dimensional systems theory. Several of Inaba's joint projects are with two of his bright and very promising research students and colleagues, Mr. N. Otsuka and Mr. Ito. Their work makes heavy use of tools from linear algebra and operator theory. My research interaction with this group was mainly on linear algebraic aspects of the problems they are working on. This group is becoming increasingly interested in numerical aspects of control and systems theory research.

University of Tokyo

My hosts at the University of Tokyo were Profs. Masao Iri and K. Murota, both from the Department of Mathematical Engineering and Instrumentation Physics. Iri is very well respected throughout the whole country as a pioneer in mathematical engineering education in Japan. Both the mathematics and engineering communities in this country owe a lot to Iri. He stimulated the interest of mathematicians to solve real-world problems and educated practicing engineers to acquire appropriate mathematical knowledge in their areas of research and applications. Iri also contributed profoundly in the growth of mathematical programming in Japan. He is also internationally well known for his scientific contributions in several areas of mathematics and engineering, such as network flow, graphs and matroids, numerical methods, computational geometry, and mathematical programming. He has delivered numerous invited lectures in many prestigious international conferences and serves on the editorial board of several distinguished journals, including the *Japan Journal of Industrial and Applied Mathematics* (formerly the *Japan Journal of Applied Mathematics*). He wrote a book titled *Network Flow, Transportation and Scheduling: Theory and Algorithms* (Ref 9), following an invitation by the celebrated mathematician Richard Bellman.

Prof. Iri, like me, is very much interested and quite active in bridging the communication gap between mathematicians and engineers. As I remarked earlier, this gap is very much noticeable in the West, but I learned that this is also true in Japan. A major difference here is that Japanese practicing and research engineers are far more motivated than their Western counterparts and more knowledgeable in the mathematics they have been using in their work.

Prof. Murota, a former student and a current research collaborator and colleague of Prof. Iri, is mainly interested in matroid theory and its applications to systems theory. Tools here are combinatorial in nature. This is a very interesting and innovative approach to solving systems theory problems; however, I am not sure if it will have a long-time impact in systems theory research. I am not aware of any people in the West currently active in this research.

Conclusions

From the brief interactions I had with the Japanese scientists, I have the feeling that Japanese mathematicians, control theorists, and engineers are very active in almost all areas of theory and applications of control theory: H_∞ control, robust control, adaptive control, infinite dimensional systems theory, abstract control theory, robotics, etc. In fact, as far as industrial applications of control theory techniques are concerned, Japan seems to be ahead of all the Western countries, including the United States. However, surprisingly, there are very few activities in the computational aspects of control and systems theory--especially, there are almost no activities in the area of large-scale and parallel computations in control. As mentioned earlier, all the current activities in this area (though they are very limited) are in the Western world, mostly in the United States.

SITE VISITS TO HONG KONG, MACAO, SINGAPORE, AND INDIA

Hong Kong

In Hong Kong, I visited City Polytechnic of Hong Kong and the University of Hong Kong. In City Polytechnic, my host was Dr. Daniel Ho of the Department of Applied Mathematics. I found this department very active in applied research and several members of the department are internationally visible. Their research interests include scientific computing applied to transport modelling, computational fluid dynamics, vibrating systems, heat transfer, computational aspects in control and systems theory, optimization theory, etc. Ho is a specialist in computational and applied control theory. He has published joint papers in the area of H_∞ control theory, output feedback problems, computer-aided control theory, etc. in collaboration with some internationally known mathematicians and control theorists such as Fletcher, M.J. Grimble, etc. His research is funded by research grants from the Polytechnic.

Ho belongs to a group working on scientific computation and its applications led by Prof. James Caldwell. One of Caldwell's strengths is to attract researchers from engineering and other applied science areas to work in the area of applied mathematics. For example, his joint work with Dr. Y.M. Ram, a mechanical engineer, has resulted in publications in several SIAM journals in the area of vibrating systems. Caldwell's research is funded by overseas agencies.

My host at the University of Hong Kong was Dr. Raymond Chan, a young numerical linear algebraist who has already received international

recognition by winning the prestigious Fox Prize. His research interests include numerical linear algebra with applications to differential equations and signal processing. He has collaborated with well-known numerical linear algebraists such as Robert Plemmons.

The department is active in research both in pure and applied mathematics. Some of the internationally recognized researchers of the department are Drs. Y.H. Au-Yeung (linear and multilinear algebra), M.C. Liu and K.M. Tsang (analytic number theory), K.Y. Chan (differential equations and mathematical modelling), M.K. Siu (combinatorial number theory), S.C.K. Chu and T.G. Yung (operations research applied to mathematical modelling), and Dr. R. Chan (numerical linear algebra, numerical differential equations, signal processing, etc.). The department is headed by A.J. Ellis, who pursues his research in functional analysis and convexity theory. Over the years, the department has produced many mathematicians who now hold important positions in business, government, and education, both locally and internationally. Many of their graduates hold professional appointments in some of the leading universities of the world, such as Harvard, Stanford, and Berkeley.

In conclusion, Hong Kong seems to be in the forefront of research in modern mathematics and scientific computing. There are adequate research and computing facilities and there is a sincere desire to expand their research horizons and be recognized in the Western world.

Macao

During my stay in Hong Kong, I made a 1-day trip to Macao to visit the University of East Asia. This university is relatively unknown to the world. My host was Prof. Graciano de Oliviera, an internationally reputed linear algebraist from Portugal who has been a visitor to the university for the last year. He and his wife, who is a numerical analyst, are trying to build research in certain areas of mathematics, especially in the area of linear and numerical linear algebra.

Singapore

In Singapore, I visited the Mathematics Department of the National University of Singapore (NUS). My host was Dr. Tara Nanda, a numerical analyst, who received his Ph.D. from the Courant Institute of Mathematical Sciences in New York and did post-doctoral work with Prof. Beresford Parlett at Berkeley. Nanda is currently engaged in developing an interactive educational software package in numerical analysis, which appears to be very interesting and innovative. The researchers at NUS have access to national supercomputing facilities, however, the facilities are underused.

I found, to my distress, that their program for visitors is not well organized. Occasionally, the university spends a huge amount of money to bring very distinguished visitors such as some Nobel laureates, which is fine, but not of much help to build research. A systematic program to bring active researchers from around the world to help build research in certain focused areas is lacking.

India

I visited India upon an invitation from the Government of India to be a scientific advisor. My visit was funded by the United Nations Development Plan. This was indeed an extremely well-organized program. I spent the first 2 weeks in the city of Bangalore, one of the most prominent centers for scientific research and technological development in India.

I was officially hosted by the Department of Computer Science and Automation of the Indian Institute of Science (IISC). My host was Prof. N. Viswanadham, an internationally renowned control theorist. I visited several departments in IISC such as the Institute for Supercomputing Education, headed by Prof. Rajaraman, and the Microprocessor Applications Laboratory, headed by Prof. Patnaik. I also visited several government-funded research laboratories in Bangalore, including the Center for Development of Advanced Computing, headed by Dr. U.S. Shukla; the Central Research Laboratory of Bharat Electronics (Ref 10), headed by Dr. Paulraj; the Center for Artificial Intelligence and Robotics, headed by Dr. M. Vidyasagar; and CMMACS at the National Aeronautics Laboratory, headed by Dr. K.S. Yajnik.

My visits to these places revealed that India is in the era of supercomputing. India has acquired a Cray from the United States recently and this is being used in weather prediction research at the Indian Metrological Department in Delhi; the Supercomputing Institute at IISC is in the process of getting a Cray-XMP from the United States. Other parallel computers, especially the distributed computers, are presently planned to be bought. Besides these, India has already built a transputer-based, Hypercube type, distributed memory computer, PARAM, at the Center for Development of Advanced Computing in Pune and is in the process of building others in Bangalore and other places. These computers are presently being used in applied research such as speech synthesis, pattern recognition, power systems analysis, image processing, robotics, radar signal processing, artificial intelligence, space research, oil reservoir modelling, seismic data processing, etc. (Ref 10). One bottleneck in using these computers has been the lack of suitable parallel mathematical software. Indian scientists have been trying to develop some, but that will be a challenge. Besides these, several microprocessor-based architectures and appropriate software

are being developed, notably at the Microprocessor Applications Laboratory in IISC.

The last 2 weeks of my visit were spent at the Indian Institute of Technology, Kharagpur, in West Bengal, India. I was hosted by Prof. Kanti Bhusan Datta, a well-known control theorist in the Electrical Engineering Department. I visited the Departments of Computer Science and Mechanical and Aerospace Engineering. I found there was a sincere desire among the engineers and computer scientists to develop collaborative research blending mathematics, computer science, and engineering. I was invited by the director of the institute, Prof. K.L. Chopra, to help them set up a center for interdisciplinary research with a strong focus in scientific computing. I shall be seriously considering this.

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STATE OF THE ART IN JAPANESE COMPUTER-AIDED DESIGN METHODOLOGIES FOR MECHANICAL PRODUCTS -- INDUSTRIAL PRACTICE AND UNIVERSITY RESEARCH

The author spent 3 months in Japan as a temporary liaison scientist with the Office of Naval Research Asian Office to survey Japanese use of computers in design of mechanical products, to report on the state of practice in Japanese companies, and to determine research needs and trends in both industry and academia. The resulting report contains a thorough mix of engineering, management, science, and technology issues.

by Daniel E. Whitney

INTRODUCTION

I spent from 3 June to 13 September as a temporary liaison scientist at ONRASIA, the Far East office of the Office of Naval Research, while on leave from the Charles Stark Draper Laboratory, Inc., Cambridge, MA. ONR asked me to survey Japanese use of computers in design of mechanical products, to report on the state of practice in Japanese companies, and to determine research needs and trends in both industry and academia.

The resulting report contains a thorough mix of engineering, management, science, and technology issues. This is appropriate for manufacturing, a complex and challenging area where practical solutions are often needed before theoretical understanding is available, and where major innovations have come from practitioners. Research often plays the role of replacing the idiosyncratic nature of these solutions with an intellectual foundation and making them available to a larger community.

Japanese companies have approached manufacturing with skill and depth. Many of their solutions go beyond the usual day-to-day and include significant long range thinking, providing clues to the nature and structure of the underlying intellectual issues. A major objective of this report is to present these challenges and responses in the hope of informing both the industrial and research communities about where some of the world's best companies think the frontier problems are and what they are doing about them.

BACKGROUND

This is my seventh visit to Japan since 1974, but the first to last more than 2 weeks. My research interests are in robotics, computer-aided design (CAD), product design methodologies, design for assembly, and the relation between technical and business aspects of product design. On prior visits I have regularly visited the same laboratories, companies, and people over and over. The reason is to follow the maturing of the people and the companies and the evolution of their approaches to generic problems. The topic of discussion on prior visits usually was robotics and its application to industrial assembly.

On prior trips I visited mostly industrial sites because I found that industrial people were closer to real problems and solved them with remarkable ingenuity combined with significant intellectual depth. This contrasted sharply with university research in robotics, which in my view (in the United States as well as Japan) tended to focus too much on far advanced technology and attempted to solve all robotics problems by enhancing the technology of the robot. Industry took a more balanced view and attempted to improve

robot technology in feasible as well as economically high-leverage ways (mostly by increasing motion speed) and improve robot applicability to tasks by redefining and redesigning the tasks (mostly by pervasive and thoughtful product redesign). This combination has proven to be very powerful. I have written about this contrast in several venues (Ref 1).

On this visit I have focused on design and found the universities to be more interesting than before, largely because they have tightened their contacts with industry and have identified several very relevant research tracks that should flow directly to industry very soon. Still, companies are on the front line of design and have, as in robotics, applied considerable intellectual force to defining their problems and evolving impressive responses.

Companies visited represent heavy, medium, and precision industry. I identified many of them from prior visits, while others were identified and contacted by Prof. Fumihiko Kimura of the University of Tokyo, whose collaboration is greatly appreciated.

CAVEATS

In a 3-month visit, it is not possible to obtain a statistically significant sample. I visited companies and laboratories that are leaders in one way or another. A typical visit took most of one day and involved from 3 to 10 company personnel. While they hosted me attentively (in some cases lavishly), they did not have time to tell me everything and in no case did they place anything on the agenda that had not been published or discussed with outsiders before. I am certain they were frank and responsive to my many questions, however.

Where capabilities or activities of different companies are mentioned below, they should therefore not be taken as having comparative value. That is, if company A mentioned capability X and company B mentioned capability Y, that means X and Y are being pursued in Japan, not that company A lacks capability Y.

Similarly, just because a Japanese capability is mentioned does not mean that this capability does not exist in other parts of the world or that other countries' companies and universities are not ahead in some areas. No time was available during this study to make comparative assessments of European or U.S. companies or universities, even though many excellent ones exist.

TYPES OF PRODUCTS COVERED IN THIS REPORT

Fifteen companies were visited, some more than once. A breakdown of types of products (with number of visits in parentheses) is as follows:

- Heavy industry - machine tools (3), cars (5), aircraft engines (2), construction machinery
- Medium industry - car components (2), home appliances (1)
- Precision industry - video cameras (3), disk drives (2), dot matrix printers (1), cameras (2)

Three visits were made to industrial research and development (R&D) laboratories that create computer design tools and eight visits were made to university laboratories that do robotics or design research.

INFORMATION SOUGHT ON THE VISITS

My long-term research interests focus on how to structure design processes so that they achieve products that can be easily made, sold, repaired, upgraded, and so on, and to create computer tools to aid the design process in these ways. Japanese companies are well known for being able to design high quality products, to perform the design process rapidly, and to manufacture the products efficiently. Japanese manufacturing methods have been extensively studied, but the supporting or enabling character of the product designs themselves has not been emphasized in those studies. Thus the methodologies of the companies in meeting the design challenge are of great interest.

When visiting a company, I tried to determine information of the following kind:

(1) What is the main outline of the product development process, starting from conception and concluding with construction of the manufacturing facility?

(2) What computer tools support this process and where do they come from?

(3) How long does the process typically take and how many engineers are involved?

(4) How are the needs of manufacturing and other interests integrated into the design process and how are the inevitable conflicts between performance, cost, and manufacturability resolved?

(5) What are the main challenges to intelligent and successful product design (for example, dealing with product diversification, taking account of business forces, working with designers in different countries, deciding how to use automation effectively, and so on) and how do the companies plan to meet these challenges in the future?

The visits were arranged by means of a lengthy letter spelling out my aims and interests. The actual interviews were not accompanied or preceded by lists

of set questions, and each company constructed its own agenda, subject to minor changes by me, to suit its own ability or inclinations. Usually, the company and I exchanged informal presentations, followed by laboratory tours and general discussions. In most cases, these discussions were quite exploratory since the companies are also interested in the above questions and constantly evolve their ideas. They also want to know what U.S. companies are thinking and doing.

SUMMARY FINDINGS

Company Methods and Priorities

1. The most advanced companies take a total view of manufacturing; they are vertically integrated in the skills and facilities of product realization. These are too important to be given to vendors.

    - They write most or some of their own three-dimensional (3D) computer-aided design (CAD) software as well as many computer-aided manufacturing (CAM) and computer-aided engineering (CAE) applications, which are tightly prioritized and focused on their own careful formulation of their internal design processes.

    - These companies, and others less advanced, make most of the critical manufacturing equipment they use and buy many low-value-added components for their products; most U.S. companies follow the opposite strategy, making components and buying equipment.

2. Most companies continually study and refine their design processes, information flow, CAD/CAE facilities, and design management methods, striving for major improvements in design time, design cost, and product cost.

3. One-third of the companies visited have developed their own design for assembly (DFA) methods and software; in some cases DFA is used in the traditional way to simplify the product's assembly, while in others it has been reformulated and elevated to a new status of enabling new manufacturing strategies or focusing conceptual design efforts.

4. Every company wants to design products faster, even though they are already the fastest in the world.

    - This requires vastly increased ability to predict performance and fabrication/assembly problems and costs very early in the design process.

    - The main strategy in use to design faster is to begin designing manufacturing systems and equipment before product design is finished; this is called "overlapping tasks."

    - Using incomplete information in this way is risky and requires intense human communication and carefully supervised release of partial design information; most companies say that designers' experience is the crucial factor in this process, not use of computers.

    - Most companies have used cross-functional (i.e., product and process) design teams for years and also cross train their engineers; the term "concurrent engineering" does not mean cross-functional teams but instead means beginning production system design well before product design is finished.

    - This process has not been perfected and many barriers between disciplines and departments remain.

5. Companies boast of the strength of human communication and experience in explaining their design prowess, but underneath they worry about how to transfer this experience to computers. No intellectual basis for accomplishing this transfer is emerging from industry, but it may be in university research; instead the companies learn by doing, both in new CAD and in new manufacturing methods.

6. Japanese design teams are surprisingly small; except for cars, no team for products like cameras, copiers, printers, car components, or videocameras (up to 1,000 parts each) was larger than 30. Computers are unlikely to be of help purely for communication within teams, and this particular use of computers may be what the companies feel is not useful.

7. Every company has trouble finding new engineers (except Sony); increased design automation is the main response, but capturing real knowledge and experience is a serious barrier, and the overall quality and experience of some companies' design staffs may be slipping.

8. Another way the companies attain rapid design is to overwork their engineers; long workdays and small design teams are effective but take their toll in other ways (fatigue, mistakes, difficulty hiring new engineers).

Computer Capabilities

1. Most companies use commercial CAD and CAE software made in America and many run it on U.S.

mainframes or workstations; the applications are typical.

- The depth of penetration of CAD and CAE (numbers of terminals, degree of paperless operation, number of CAE examples) is impressive, even in small and medium size companies.

- Every company visited (ranging from 1,700 to 250,000 employees) has equipped its designers with networked CAD systems; as many as 1,000 terminals and 3,000 PCs on networks are found in large companies.

2. Current commercially available CAD is weak in representing engineering information and in supporting process design and production engineering; it is strong only in drawing pictures.

3. The best CAD observed was realistic rendering, and the best CAE observed was integrated car body styling, body engineering, and stamping die design and manufacturing; both of these were in-house developments.

4. Companies feel that commercially available 3D solid modelers are too hard to use and cannot represent parts and products in sufficient detail to permit serious process analysis without bogging down under all the data, wireframe models are unintelligible to anyone except the original designer and thus are useless for cross functional communication.

5. CAE of products and computer-aided design of fabrication and assembly processes are either not performed at all or are done in a nonintegrated way using collections of different stand-alone software sometimes linked by awkward data conversions; the exception is a few application-specific design systems written by the most advanced manufacturing companies themselves.

Research Priorities

Research in design worldwide focuses too much on long range but narrow engineering problems and not enough on the combination of engineering and management problems facing industry.

- Overemphasized areas include rendering, sculptured surfaces, and metal-removal process planning; the advanced companies are often ahead in these areas.

- Underemphasized areas include organizing information flow; creating cross-functional design/engineering computer models of products; rapid prototyping; prediction of cost, performance, and manufacturing problems during concept design; tolerance modeling; improving 3D user interfaces; deciding when production issues should enter the design process; and defining criteria for balancing such issues against product performance.

UNDERLYING THEMES

Japanese companies' achievements in design and manufacturing warrant study. In approaching this project, I formulated several underlying themes in the hopes of fleshing them out. Readers of this report will find me returning to these issues repeatedly.

- Management style versus CAD
- What is manufacturing, what is design
- Role of research at universities
- Structure of the CAD industry

Management Style Versus CAD - Which is More Important?

The business schools and the engineering schools have differing views of product design. Several business schools, notably Harvard and the Massachusetts Institute of Technology (MIT), have extensively studied the world automobile business to determine why the Japanese auto industry can deliver new models faster than their European or U.S. competitors. The marketing value of doing so has long been recognized, and Japanese companies in other industries such as laptop computers and consumer electronics are similarly adept. Prof. Kim Clark of Harvard and his former student, Prof. Takahiro Fujimoto, now at the University of Tokyo, say that the main reason is specific management methods such as overlapping design tasks that are normally done in sequence (Ref 2). In offering such explanations, the business researchers tend to ignore or downplay the role of computer design aids, such as computerized drafting, solid modelers, data management, rapid electronic communication, and so on. Several companies agree.

Engineering schools and researchers tend to ignore the management factors and look exclusively at the computer tools. To put the contrast bluntly, the business researchers think computers are commodities that anyone can buy and use, while management techniques are the product of decades of "corporate learning" that others cannot buy or copy. The engineering researchers feel that management practices can be copied and learned, too, or are merely "social factors," whereas design and manufacturing engineering software, knowledge, and data about past designs, properly captured and deployed in computers, can convey considerable competitive advantage in terms of design speed, accuracy, and quality. Toyota

says its integrated CAD/CAM system for stamping die design and manufacture has shortened this process by 23%. Most companies also stress the long-term "corporate learning" that has gone into building their engineering experience and several databases of this experience that they have created.

In the following pages, readers will find plenty of evidence for both positions; opinion among the Japanese is divided and discussion is lively. However, the Japanese tend to emphasize what they have already achieved and de-emphasize what they are still developing and cannot yet show proudly. Management techniques, therefore, get the credit while computer aids take a definite second place. Also, they tend to develop a process manually first and understand it thoroughly before attempting to computerize it. This contrasts sharply with a U.S. tendency to computerize things right away.

A story will illustrate the issues. About 7 years ago, Nippondenso gave me a tour of their assembly line for alternators. These alternators are mainly sold to Toyota, which uses the Just in Time (JIT) production method. Nippondenso uses JIT also. JIT runs on production order tickets called Kanbans. I saw bundles of Kanbans in the form of IBM cards being carried around Nippondenso's plant, never being unbundled much less used in a card reader. I was told this was sufficient since the strength of JIT was its ease of understanding and low technology. Seven years later Nippondenso proudly showed me a video of their modern approach to manufacturing, in which Kanbans are read optically or magnetically and all the data are funneled into a central computer for instant oversight and redirection of resources.

Finally, it should be noted that considerable misunderstanding can arise during discussions with Japanese engineers and managers concerning computers The Japanese think of computer aids in three categories: data management, design software, and communication between designers. They tend to call the last one "concurrent engineering" software, a confusing and limited definition. They tend to want to avoid computer communication and so they often say they do not see the need for computer tools for concurrent engineering. It takes a lot of discussion to clear up this issue. Then they tend to agree that they can use all the engineering design and manufacturing/assembly software they can get their hands on.

In this report, the importance of management methods has been acknowledged and used to counterpoint typical engineering approaches to improving design. Ways in which useful management methods can be augmented by computer tools have also been pointed out. It is the author's opinion that a combination of management methods, engineering design, and computers is extremely potent, and collaboration between researchers in both domains will prove to be productive.

What is Manufacturing, What is Design

"Manufacturing" used to mean metal removal or metal fabrication. In the United States, the word has gradually gained generality, but only a few people associate it with all the processes required to make a product. In Japan, among the most sophisticated of industry, university, and government people, "manufacturing" means all the activities of a manufacturing company, from marketing studies to shipping the product and following it up in the field. Financial and management factors must be included. There is no boundary between them in the companies even if there is in portions of the research community. Any serious research in design that will attract industrial interest must take this totality into account.

The unity of design and manufacturing is explicitly recognized in the Intelligent Manufacturing Systems (IMS) proposal recently promulgated by Japan. The IMS is centrally focused on design because design creates the conditions under which fabrication, assembly, test, and use occur. The broader term "product realization" is used among university researchers to capture this process and place it in the joint engineering-business context.

Role of the Universities

University research on design in Japan is supported by many large and medium size companies who either join specific consortia initiated by one professor or who contribute equipment to a professor's laboratory. Government support is growing, although budgets are restricted at the national universities. The engineering and business schools take separate tracks much as the U.S. ones do, but in both areas a lot of the research seems well targeted on industrially relevant problems and has a near-term character similar to what one sees in Germany. Most of the leading professors do extensive consulting, often including monthly meetings with industry. Such contact tends to produce focused research that companies will recognize as relevant.

The companies have identified many longer term problems that the universities are working on to varying degrees. Seemingly whimsical wishes ("push a button and out comes the design") are offered seriously. However, in most cases, the companies do not have a strategy for attacking these problems or a vision or intellectual synthesis of potential solutions. Furthermore, they do not yet recognize the power of current research to bring some of those problems under control.

A core goal of long-term design research is to flesh out the idea of a computer-based "product model" that will link specific market and engineering specifications for a design object with general company design and

manufacturing knowledge and capabilities. Knowledge is defined very broadly as including expertise, test data, past designs and their field performance, deep engineering understanding, catalog data, government regulations, and company standard practices and design rules. The companies do not yet think in quite these terms and currently see wide area distribution of, and common access to, existing conventional CAD data as their main problem.

Structure of the CAD Industry and Technology Transfer Routes

Japan does not seem to have a CAD industry such as the United States or Europe has. Companies comparable to Computervision, Structural Dynamics Research Corp. (SDRC), and Mentor Graphics do not exist. No Japanese workstation has yet gained the popularity of those made by Sun or Hewlett-Packard. Japanese companies have taken three routes to obtaining CAD and CAE: buy hardware and software from the United States, invest over decades in writing their own software, and a hybrid of these. Companies that write their own face the problem of long-term support as technology and needs change, such as migrating to new hardware and integrating new programs into their existing software. But they have developed at least near-term solutions for these. (Nissan and Toyota have joint ventures with IBM and Unisys to support their home-grown CAD and sell it to their suppliers.) Companies that buy from the outside must accept their vendors' solutions to these problems and most have switched vendors at least once, a painful event. New switches will occur as workstations replace mainframe computers.

As research produces new CAD/CAE/CAM tools and methods, an efficient technology transfer route needs to be developed. The rich companies that write their own can support their own university research and insist on compatibility. Those that buy must rely on the software vendors to keep aware of research results and incorporate them into their product line. This route will not provide CAD buyers with the competitive advantage they need unless a variety of easy knowledge capture, data management, and software integration tools is also developed. Thus useful design research must be broad enough to recognize these as allied and essential issues.

U.S. and European companies face the same problems, of course, so solutions developed in Japan will be of great interest to everyone.

CURRENT PRESSURES ON JAPANESE INDUSTRY THAT AFFECT DESIGN PRACTICES OR SUGGEST RESEARCH ISSUES

Japanese society is changing rapidly. Some trends visible now are recent while others date back years or decades. Those that follow were brought to my attention during my visit but are echoed in many publications, most recently in Reference 3.

Labor Shortage

Japanese industry has faced chronic shortages of factory floor labor since the early 1960s, when it was forecast that the gross national product (GNP) would grow faster than the population. This has forced pervasive and relentless automation onto Japanese industry, which has, in turn, forced a revolution in how products are designed. Now the shortage has extended to engineers and scientists. Indeed, the birth rate is now 1.53 children per couple, and Japan faces falling population in a few decades. To maintain the standard of living, automation will have to extend to the field of design. Companies are seriously worried about capturing the experience that they now boast of and converting it to computer form so that junior engineers can do the work of rapidly vanishing senior people.

Deterioration of Lifetime Employment

Professionals are starting to discover the advantages of job mobility. At least 5% of employees voluntarily change jobs each year and the number is rising. Headhunter firms are springing up. An important result is that future design activities may not be carried out by people who have known each other for years. Risky design methods like task overlapping (see below) are likely to suffer. Computer design aids could help but the companies do not yet want to place strong reliance on them.

Shortening the Design Cycle

At the same time as the number of engineers is threatening to fall, the measure of competition has become rapid introduction of new products and new versions of existing ones. Companies have responded by intensively studying their organization and design process, automating key portions of the process, innovating management methods, and overworking their engineers. Some are having such trouble recruiting new hires that they give new graduates vacations to keep other companies from locating them. One company gives a car to each new hire. Several companies I visited spoke openly of lengthening the design cycle, possibly by silent industry-wide mutual agreement. Others resort to cosmetic redesigns, postponing more thorough efforts. While several companies presented their computer design aid activities as being targeted at shortening the design cycle, others de-emphasized the issue because it is politically sensitive.

Work Style, Work Life

As mentioned above, Japanese companies overwork their engineers, who in turn cannot decide if loyalty or resentment is the right reaction. Younger people are starting to rebel, and the government wants the working year reduced to the U.S. average of 1,800 hours by 1993, from the current average of 2,000 (2,200 or more in the high tech industries). A friend termed Japan a "herd society": once a trend starts, everyone joins in. If young people abandon engineering or refuse to work as hard as the previous generation, a crisis will occur.

Globalization

Japanese companies are finding that they cannot export their management methods to their branches in the United States and Europe. Overlapping of design activities is a risky approach since it requires starting a job before all the necessary information is available. Careful structuring of the design process, identification of the crucial information, and steady, deep communication between designers are required to keep serious errors from occurring. Non-Japanese engineers are not used to such communication, they shun the risks of this approach, and they do not work long enough hours to accomplish it. Few companies outside Japan study and improve their design practices. Shared design projects, therefore, become uncoordinated as the foreign parts slip behind schedule. Research in design methodologies to overcome this kind of problem is not being attempted to my knowledge.

THE MAIN INTELLECTUAL ISSUES

How Japanese Companies Approach Product Design

Definition of a Manufacturing Company. Several Japanese companies take a total view of their existence as manufacturing companies. They not only develop their own CAD software but also the most critical elements of their manufacturing and assembly equipment. On the other hand, they buy many of the components that go into their products. This keeps design staffs small (see below) and focuses the company on the essentials. That is, they are vertically integrated in the essentials of product realization and see this end-to-end capability as a major competitive strength. U.S. companies are often vertically integrated in components and tend to buy their manufacturing and design facilities from a fragmented and undercapitalized vendor community. The Japanese approach reveals a stronger commitment to internal manufacturing excellence and provides vastly better opportunities for communication between product and process designers. It also provides funds for new process development and drives ongoing learning of better product realization methods and technologies. As one person put it, "You learn by trying, not by buying."

Consistent with this commitment, many Japanese companies maintain production engineering as a corporate headquarters activity; it is often represented by an executive director, equivalent to an executive vice president in a U.S. company. Thus production engineering has a strong voice at the very top of the company. U.S. companies are often product-line oriented. Each product division has a voice at the top while production engineering is a function located at each factory. Its job is often merely to maintain purchased equipment.

Toyota and Nissan provide most of their own CAD software, while Nippondenso provides a significant portion of its. Sony, Hitachi, Seiko-Epson, Fujitsu, and Nippondenso make their own robots (over 3,500 at Nippondenso and currently increasing at 1,000 per year). Matsushita makes its own circuit board assembly equipment. Some of this equipment enjoys strong outside sales, strengthened by in-house experience with its use. Sony has trouble selling its robots, and Nippondenso doesn't bother selling. Toyota and Nissan have commercialized several of their CAD programs, but only for the purpose of getting their suppliers to use them, not for general sale. Data and software compatibility is the goal.

Most of these activities date from the mid 1960s to early 1970s and appear to be unbroken, growing programs with long-term perspective and full top management initiative or support. Major objectives are set (extend ability to automate while attaining xx level of flexibility, or permit early detection of the most time-consuming kinds of design errors or uncertainties in car body engineering), and bit by bit they are attacked over many years.

Toyota, Nissan, and Nippondenso appear to have long-term strategies for allocating resources to computerization of the design process. For Toyota and Nissan, the focus is on the engineering-intensive and time-consuming process of body styling and engineering, which normally suffers from huge data requirements and much trial-and-error. For Nippondenso the focus is on supporting both routine mechanical design and breakthrough product-process design for flexible production. Trial-and-error is not a big issue.

All three seem to favor achieving some level of end-to-end integration from concept to production engineering using admittedly approximate methods rather than delaying integration while perfection is reached in each of

the calculation steps in this process. All companies visited also recognize the need to provide all engineers with access to computers. The ratio of engineers to terminals varies from 5:1 to 3:1 with 2:1 or 2.5:1 being considered optimal.

Smaller companies naturally cannot afford such activities, but many in the range of 13,000 to 35,000 employees make their own CAD software and most in the 4,000+ employee range make key manufacturing equipment. An interesting exception is Mazda, which is selling off machine tool and transfer line divisions and using the funds to "in-source" some high tech, high value-added components that they once bought. This is the route of "survival" in their view.

Systematic Approach. Every company I visited has a systematic, step-by-step plan for how products are designed. This is typical and not surprising. There is often a set of two to six prototypes spaced out at intervals during the process. Companies differ on when is the right time to introduce manufacturing and cost constraints and when to involve manufacturing engineers and factory personnel. The prototypes are often given names like "research," "function," "manufacturing," and "preproduction." When the product is a very new one, such as a videocamera, computers play a limited role (e.g., verifying the precision of tape threading) until the function prototype is finished, at which point CAD is used to document the design and support further engineering. When the product is an ongoing type, such as a car, the most advanced companies design the first prototypes directly into a CAD system. This statement applies to both totally new body styles and rather repetitive suspension components.

At Nissan, the first prototypes are built at the design center, whereas the last are made at the factory by manufacturing engineers or line workers. At Hitachi, VCR mechanism designers build the first prototype with their own hands. At both companies, design responsibility shifts from the advanced design office to the factory's design staff beginning with the manufacturing prototype. At Nippondenso, the design process is so closely tied to increasing automation that process engineers are involved from the first day so that the necessary novel process methods can be developed. At Sony, product function designers are led by someone with at least 10 years' experience, and they take account of assembly sequence and assembly-related tolerances during functional design. Hitachi and Nippondenso have each evolved rather different design evaluation techniques for improving assembly. Neither has integrated them with CAD but both would like to. Companies disagree widely as to whether functional designers should be equipped with computer tools to critique manufacturability and assembleability of their designs, or whether these tools should be used by process engineers. Sony and Hitachi take the former view, while Toyota and Nissan take the latter. The difference perhaps reflects the different time scales for design (only a year or two for videocameras versus 4 years for cars).

The more sophisticated companies constantly review their design practices, including their deployment of computers. At Ishikawajima-Harima Heavy Industries (IHI), the process is being restructured using the critical path method (CPM) in order to cut the time. The idea is to carefully identify the information that each design step needs from prior ones and provides to later ones, plus when that information is needed or available. The information is ranked by importance or leverage and only the most important items are included in the CPM analysis. A tight flow of the most crucial information thus can be used to resequence the steps to produce a faster process. While no other company cited formal analytical techniques, most are involved in ongoing or recently launched reevaluations of their design methods with the aim of reducing either cost or time or both.

These "restructurings" and "reformulations" of the design process are intellectually challenging and involve defining new work styles, data requirements, and software support requirements. "We used to buy software and adapt our work style to it," says a CAD director at Nissan. "Now, we will define our next generation work style and obtain or write software to suit."

Many American companies went through "painful" reformulations of their engineering design methods in the early 1980s and typically report that they are now satisfied with the results. Japanese companies are never satisfied.

Integration of Engineering and Business. Many of the companies visited have identified a theme for their business that is reflected in their efforts to deploy computers and other automation. At Nissan, this theme includes world-wide design activities with uniform standards, techniques, and supporting software. At Nippondenso, the theme is to conquer product diversity efficiently in a mass-production environment using a combination of product and process design. At Mazak it is to be the prime user of the manufacturing equipment it sells, both to gain experience and to act as a living laboratory for its customers. The machine tools it makes, interestingly, are rather ordinary, and their design is supported by only the most basic CAD. But Mazak's manufacturing automation is among the best and most well thought out in the world, and several aspects of product design are aimed at maintaining that excellence.

The consumer product companies recognize that marketing and product design are tightly linked. Nippondenso is especially good at identifying ways to design its products to meet the rapidly

varying product mix of its biggest customer, Toyota. Toshiba's laptop computer designers spend part of every week going over customer inputs so that new designs will be well received. Top executives set the specifications for the new product. At Nippondenso, the speed of the design process and the overlapped task method require top management involvement and fast decisions throughout the design process.

The long-term trend toward, and competitive advantage of, smaller, lighter, and quieter products (computers, cars, and everything between) is driving companies into more CAD and CAE. Strength, noise, and vibration characteristics of products are more critical. Lighter parts have thinner walls that vibrate or magnify noise more than heavier ones. Extensive finite element analyses are the only design tool available. Supercomputers and super workstations are being increasingly recruited.

A major theme running through this report is how to automate in the face of rapid changes in product technology and market shifts. Companies want to automate because automation is more consistent and efficient and produces higher quality than people can. But companies are afraid of being trapped with useless equipment if the product or the market changes. Researchers see this as either a problem of scheduling existing types of equipment or of improving the general technological level of equipment. Companies see it as a problem of product design, which often requires specific new production technology. The researchers' approaches are too narrow, but the companies' approaches, while more balanced and effective, lack generality. However, lack of generality may be inevitable and may never bring progress to a halt.

Integration of Product and Process Design. Japanese companies have known for years what U.S. companies once knew and apparently forgot, namely, that product and process design need to be carefully coordinated. Until a few years ago, there was no special name for this in Japan; it simply was a fact expressed by the multidisciplinary composition of design teams. Now the names "simultaneous engineering," "concurrent design," and "concurrent engineering" have come into use. In the United States these are associated with attempts to apply computers to achieve this integration. The Japanese are puzzled by this development and wonder if it is something new. Their ability to assess U.S. activities is limited and I was questioned repeatedly on this point.

Many companies actively fear an invasion by computers into their human communication methods, thinking the United States will catch up and that computer communications will be too weak to support the intensity that Japanese currently achieve. (See below for discussion of small design teams.)

Success at product-process integration requires identifying just what information the downstream process designers will need from the upstream product designers, and vice versa. In the absence of a structure for this data exchange, integration degrades into arguments and confusion. While the priority is usually given to achieving the desired function, some Japanese companies are now so sophisticated that they can tailor product designs to favor some very efficient and flexible manufacturing methods without impacting performance at all. Nippondenso is the best of these among companies I visited. The research community has barely recognized this issue. Potential approaches include information analysis of design processes, cost structure analyses of fabrication and assembly, and modularization methods for products.

Overlapping Tasks. Overlapping design tasks, described above, presents numerous problems. Some academic researchers in engineering predict that overlapping can be used only on repetitive products like cars where there is a well-developed design process in place. However, Nippondenso claimed that it uses this method when developing quantum step improvements in existing products, an effort that means total redesign and many new manufacturing and assembly processes.

To support overlapping with analytical and computer methods requires creating ways to systematically detect and structure data and information flows in ways that are more sophisticated than IHI's methods for resequencing. Right now, all the companies depend on communication between engineers who have worked together for years. They can anticipate each other's actions and compensate ahead. For example, a stamping die designer can peek at a car panel design and see trouble in one region. He can then leave this region blank in his die design or can have the die made with extra metal in that region that can be removed later when the precise body shape becomes known. Often stylists will not permit outsiders to peek at their unfinished designs since they do not want to be blamed if the design changes later. Long association creates the necessary trust.

One should not conclude that the companies depend solely on this unstructured communication. In fact, Toyota insists that all information release is approved, but incomplete or preliminary information can be released with only low level approval whereas final information requires high level approval. Mazda has a highly structured set of over 20 design reviews that guarantee input from and information for all the relevant departments.

Small Design Teams. At many companies, the number of designers and engineers assigned to one product seemed small. For example, the rough statistics in Table 1 apply to product function designers designing new products (not minor redesigns of existing ones) at several companies visited.

The figures in Table 1 accurately reflect the total manpower employed. Few or no assistants such as draftsmen are used.* "Engineers make their own drawings." Technicians and test engineers for laboratory evaluations of designs are not included, however.

Part count in these products (except cars) is in the range of 100 to 1,000. As a rough average, one designer may be responsible for 20 to 50 parts. These statistics are remarkably consistent, as are the times quoted for converting market requirements into a final product: 1 to 2.5 years for all of the above except cars (4 years).

Teams of 20 engineers are unlikely to have serious communication problems, indicating that face-to-face communication and phone calls will be sufficient and computerized methods will be unnecessary. My Japanese hosts agree with this.

The teams are small for two reasons. First, they work feverishly and accomplish a lot together. Second, large products like cars are subdivided and many common components like alternators and air conditioners are bought from suppliers. Competition among suppliers keeps quality high and permits the final assembler to focus its design staff on the core items that determine performance, namely the body, suspension, and power train. Both Toyota and Mazak go outside for many of the higher technology items like controllers, high speed bearings, and integral machine tool spindle-motor assemblies, even if the specifications for these are drawn up in detail by the buyer.

The computer issues this practice raises are long distance communication, compatibility of design data, and compatibility of design software. Suppliers with many customers for the same product line face a serious problem since they cannot be compatible with everyone. Suppliers and customers both complain about this.

Table 1. The Number of Designers and Engineers Assigned to New Products

Product	No.
Videocamera	20[a]
VCR mechanism for video camera	10
Car styling and body engineering	200-400[b]
Auto alternator	20-40[a,c]
Auto engine	30-80?[a]
Machine tool	5-10
Autofocus conventional camera	20-30[a]
Dot matrix printer	10-15[d]
Copier	30[e]
Construction crane/digger	30-40
Fuzzy control washing machine	15
Low-end hard disk drive (for PCs)	30

[a]Range for two companies.
[b]Range for three companies.
[c]Varies depending on degree of new manufacturing technology needed; includes some manufacturing engineers.
[d]Depends on complexity.
[e]For low-medium complexity.

Living With Change. Many U.S. companies structure their design processes by sequencing the tasks in the hope of maintaining control and avoiding change. This usually requires many formal design reviews and formal transfer of information packages from one stage of the design to the next. Yet changes routinely occur and have to be absorbed. When it comes to change, Japanese companies put their heads in the lion's mouth by adopting the overlapping tasks methodology. I asked repeatedly if this did not risk many design changes. In every case I was told that external pressures from the marketplace force even bigger changes on the process. The choice is to resist change or to learn how to live with, or even profit from, it. These companies have chosen the latter. Right now, as with everything, they rely on internal communication and experience, plus long hours from their staff and fast action by top management, to mechanize change absorption. Many also have elaborate document release and design review mechanisms, including attendance at reviews by designers from other projects.

No better use for computer design tools can be imagined than coping with change. Data and documents must be revised, notifications must be sent out, and new test data must be compared with old. Databases must be designed and search methods created so that people and data affected by changes can be identified easily and automatically. Design tools that permit redesigns to be made and simulated quickly are also necessary. Finally, any use of such tools to avoid extra and time-consuming prototypes in the first place makes time available for absorbing change. Many companies use the words "virtual design" or "virtual manufacturing" (the latter coined by Prof. Kimura) to describe their aim.

* In Japan, "designer" and "engineer" are synonymous. In the U.S., a "designer" is a draftsman with a high school education.

Standardization of Design Tasks. This topic, while mentioned by several companies, means something different to each. Basically, companies do not want their engineers to grope, but instead to know what to do, when to do it, and how. They want to reduce the detail that must be communicated as well as the need for lubrication from personal friendships and past design efforts. Global companies want all their overseas engineers to act like domestic ones so that their designs will be predictable and uniform. They want computer tools that contain the design process steps and have the necessary data ready for the engineer. In some cases, such as electromagnetic design (motors, alternators), companies have developed spreadsheet-like design interfaces that take in specification data and output performance curves. Only manual trade-off analyses are available so far, but design optimization is being sought. One company wants a computer system that will literally orchestrate the actions of many designers on a network, requesting parameters from them one by one, performing some portions of the design automatically, and distributing the results back along with the next round of requests. It would base this system on its existing "design standard books."

Feature-based design and constraint-based design are current research topics that have a potential bearing on standardization. These attempt to provide a designer with the ability to deal with geometry on a CAD screen that is linked to a data file of attributes which give the geometry an engineering identity. Thus a cylinder becomes a feature called a tapped hole, complete with process plan, tolerances, and assembly insertion direction. A rule or constraint can say that the hole must be at least one diameter away from the edge of the part. The data files and constraint rules underlying the geometry provide standardization and save the designer time. The rules warn the engineer if a violation occurs.

No companies have such software, and none is commercially available. However, a few companies have implemented their own primitive feature-based design for some machined items and linked it to semi-automatic, knowledge-based process planners. These computerized process plans are more consistent than those produced by human planners. Everyone asks for rule-based systems that not only warn of violations but also recommend how to change or improve the design. The difference between these two capabilities is vast.

Bottom-Up Computerization. A researcher at the IBM Tokyo Research Laboratory said to me, "The United States is too top-down oriented and Japan is too bottom-up oriented." He was referring to the two countries' different tendencies regarding use of computers. The United States, in his opinion, rushes in to computerize something without really understanding it first. Often this means converting an existing manual process, in a factory or office, step for step into a computerized one. Grave inefficiencies are often converted at the same time. A careful analysis of the requirements on the process combined with the new capabilities of computers to meet those requirements would likely produce a rather different and more efficient process. The Japanese tend to study and improve a process manually for years ("kaizen" or continuous improvement) before computerizing it. Ironically, this often produces a process that runs very well without computers. This must hurt IBM Japan's sales, but the contrast is a real and instructive one.

The attention paid to design process organization in Japan is impressive. Where computers have been applied by buyers of CAD, the applications reflect availability of software. But where it has been applied by user-developers like Nissan, Toyota, and Nippondenso, it reflects their own assessment of priorities. All companies have basic two-dimensional drafting on computer. Only a few have supercomputers for detailed fluid dynamics analyses. An informal survey of visit data indicates that product analysis has priority over process analysis and that, among process analyses, forming (cutting, molding, bending) has priority over assembly.

At Nissan, the historical sequence of computer applications over the past 30 years has been

- Data processing and coordination of test data
- Design specification control, document control, "parts trees" (what we call material requirements planning or MRP)
- Efficiency of engineering
- Higher quality (better testing, smoother outer body panels)
- Simultaneous engineering, including fusion of the above data and software
- Worldwide communication

No company visited has a common database in the computer science sense, but many use that term to describe what they have. This is usually a database that many designers can access and many software modules can read from and write to. The necessary data conversions are often error prone and time consuming, especially when manual intervention is needed, such as in meshing for finite element applications.

Description of Some of the Research Issues

Rationalization of the Design Process Itself. Many Japanese companies see study and improvement of the design process as a crucial element of corporate development. They take different approaches and emphasize different things. Few have systematic approaches. Apparently they conduct post-mortems, although no direct evidence of this was observed. The main topics I identified before and during this project are:

- task sequencing
- prioritizing design improvements
- identifying tradeoffs
- mustering experience

Task Sequencing. Understanding the design process requires seeing it in enough detail that opportunities for improvement can be identified. Saving time by resequencing has been recognized by one company, IHI, and an attempt to implement it with CPM is starting. Our own research (Ref 4) has identified an approach developed originally to help solve systems of simultaneous equations. At G neral Motors (GM), a task modeling technique developed by the U.S. Air Force called IDEF has been used to obtain and structure information about existing design procedures. No comparable methods appear to be in use in Japanese companies. Formal process representation, analysis and, especially, improvement methodologies are in their infancy.

Prioritizing Design Improvements. Setting the priorities for which areas of the process need improvement usually involves the expected factors of time and cost. Car manufacturers early identified body engineering as a long pole in terms of time and cost and have focused rationalization and CAD/CAE/CAM on it. Nippordenso studied the cost structure of automation as a function of how many models the machine was supposed to handle. They found that the cost of handling and feeding the many different parts grew faster than any other cost component. A variety of approaches is now being pursued: low cost bin-picking (a goal for a new project with no results yet) and designing so that the same part can be used in many models or so that one gripper can grasp many kinds of parts. Nippondenso's highest priority is designing product and process togetner so that a change from one model or version to another can be accomplished essentially without stopping the production line.

Identifying Tradeoffs. Functional and process designers have conflicting needs. When design begins, "fights start almost immediately." Successful negotiation of these conflicts often benefits from finding a win-win solution. In a complex design, this can be difficult to do, and zero-sum solutions often appear to be the only ones. (We need to make the product lighter, so make the walls thinner. If too much heat flows through the walls, you can just find a way to dissipate the heat.) Hitachi and Seiko-Epson have adopted the slogans "user first" and "common goal," respectively, meaning that the design team should do what will benefit the customer the most. This is a good spirit but it is not quantitative. At present, engineering models of most products and processes are too weak to permit modeling a product completely in mathematical terms, preventing use of formal analyses of mathematical structures, for example, as a way of finding tradeoff opportunities.

Mustering Experience. Every Japanese company is proud of its accumulated experience and how it is used to make better products. This is both a source of strength and of weakness. Two potential approaches to capturing this experience have been taken: knowledge capture in expert systems and data archiving. Several companies have internally developed expert systems for specific tasks (shop floor scheduling, design of turn signal lamps, layout of car trunks and exhaust pipes, machining process planning), but everyone complains that there are few knowledge engineers, and methods of knowledge capture that engineers themselves can use easily are scarce. Several companies maintain data files of test results not only for comparing new and old designs but for direct transfer into design software. None has a good way to search such databases.

Group technology (a way of coding items so that "similar" ones are in the same group) has been applied to classification of features as input to process planning systems, but companies want to be able to identify, classify, and retrieve experience in the form of past designs and process plans, which is much more ambitious.

Mazak has deployed past information about designs rather efficiently by using the "series design" method. They put considerable effort into designing a new machine and then rapidly design variants of it over the next several years by reusing existing CAD and machine performance data. The variants include larger tool storage systems, faster spindles, longer base, and so on. Six engineers can design a variant of a lathe in 2 years.

Managing Data - Integrating, Sorting, Classifying. Car, ship, and airplane designs involve huge amounts of data. More than one company said their use of solid modeling has been held back by its inability to handle the huge amounts of data efficiently. Instead, the companies must use simplified solid models or wireframes. Simplification omits some crucial details that are necessary for interference checking or

mold filling analyses, for example. Wireframes are impossible for factory personnel to interpret, impeding communication and product-process integration. Managing all this data is a serious problem. Managing it in an environment of constant change and overlapping tasks is even worse. However, one company said that it did not use a data management and control system, even though they are commercially available. This is a paradox.

Converting Experience to Algorithms. Expert systems have been used in limited ways to capture expertise at some companies. Rules, "knowledge," and formulas are combined to create a machining process planner: the rules include METCUT data and the type of tool to use in certain circumstances, the knowledge includes how big radii should be or how feeds and speeds should be chosen, and formulas calculate wear rates and tool heating.

Such applications are relatively straightforward. On the other hand, no one has a way to convert the experience of a process or industrial engineer who judges whether something is easy or difficult to make or assemble. At an auto company, we saw an assembly engineer studying a 3D wireframe model of wrench access to tighten screws on several engine compartment parts: headlight assembly, washer tank, battery bracket. All are near each other and some interfere with the tool during fastening of the others. His priority was to use the same length wrench extension for all, adjusting the assembly sequence to make it possible. This meant using a short extension, which made one deep vertical insertion almost impossible. He accepted this solution, saying that the assembler could ram the wrench down the hole faster than the acceleration of gravity, thus keeping the screw from falling out of the socket! He was not interested in my suggestion that a magnetic or gripping socket be used to hold the screw. I was told that he confers with the line foremen all the time and knows what he is talking about.

How does one evaluate whether this kind of experience and judgment is worth capturing and, if so, how to capture it and make it applicable to new tasks? One company said that all such decisions should be made based on cost. Laughter greeted my asking if they have a cost model for this.

Improving CAD for Process Engineers. Product designers have all the toys, it seems: finite element methods (FEM), supercomputers, etc. This helps them win a lot of arguments with the process engineers, who agreed heartily when I pointed this out. The first priority of the companies after supporting functional design and analysis is to make product design data available to the process engineers. Then they can at least simulate tool motions, robot actions, and cutter paths. No company I visited had fully accomplished this. The assembly engineer mentioned above had to position the wrench on each screw himself, using his mouse, buttons, and database information on the coordinates of the screw's axis. The screw head did not exist as a feature with an easily retrieved location, and no command "put the wrench on screw 22" existed. In fact, only one company showed me any assembly simulation.

No company has thought about assembly sequence analysis, much less disassembly (for repair) analysis. Nissan claimed that sequences can be worked out on the factory floor; once learned, they are not worth changing since model changeover time is too short for the necessary retraining. Sony says its engineers "know" how to plan assembly while doing functional analysis. Yet some redesign is still necessary when a product is switched from manual to robot assembly. Another company says the same thing but also remarks, "Please don't show this (design) to Prof. Boothroyd," a well-known advocate of design for assembly.

Understanding What DFM and DFA Really Mean. DFM (design for manufacture) and DFA (design for assembly) are well-known terms. They typically mean adjusting the design to make fabrication or assembly easier or less costly. I was told that our group's work and that of Boothroyd have been very influential in Japan in simplifying designs. Boothroyd & Dewhurst, Inc. and Hitachi's DFA evaluation software are popular. Sony, IBM, and Fujitsu have developed their own DFA methodologies and software.

At Nippondenso, these commercial DFA systems are not used. The explanation goes beyond the fact that Nippondenso's products apparently are a little too big in its opinion or that the rules in those methods do not seem to improve Nippondenso's current designs. Rather, Nippondenso has raised DFM and DFA to a higher level, meaning the creation of a design that permits a new kind of manufacturing strategy to be pursued.

Nippondenso has classified product flexibility into increasingly difficult accomplishments and reached each level after about a decade's work on each. The goal is to make different models of a product on the same equipment with essentially no changeover time penalty. The simplest level permits combinations of different versions of an item's parts to be assembled. The next permits different numbers and kinds of parts to be included in a housing that is always the same size. The hardest and most recently achieved permits different sizes of the same product to be made on the same equipment. Each step required increasingly radical innovations in how parts are designed, fabricated, and assembled. Nippondenso has identified increasing flexibility (or "managing diversity") as a corporate

research topic and is seeking ties with universities in order to pursue it. A collection of good internal examples is also being compiled.

Nippondenso has its own DFA evaluation method, which is consistent with the above approach. Appropriately, it spans much more than the act of mating the parts, which is the focus of the Hitachi and Boothroyd methods. Instead, Nippondenso evaluates 65 factors covering such high-leverage items as ease of switching from one model to another.

University researchers seldom have the depth of contact with manufacturing necessary to identify a problem of this type and focus on possible solutions. It has taken Nippondenso several decades to work out a long-range plan with specific steps.

Nonetheless, it is difficult to generalize from the design innovations the company came up with, except for the simplest. These are part substitution methods developed 15 years ago for dashboard panel meters. Some of the recent ones for making alternators are based on converting flat strips of raw material into fully developed nonflat, nonstraight shapes in a multistep continuous flow process almost like paper making. Prior processes were stop and go or formed pieces directly in final shape with consequent waste of material and need for lengthy die changes. A few years earlier, Nippondenso applied similar techniques to improving flexible manufacture of radiators.

Fujitsu's DFA method stands between Boothroyd's and Nippondenso's in sophistication. It classifies parts in several ways (main, subsidiary, rigid, flexible) and scores the assembleability of each class separately. Assembly time and cost are estimated. An assembly score profile results and is compared to the scores of other products. Priority in redesign is given to eliminating nonrigid, nonmain parts and to simplifying the assembly of the remainder.

Sony has a DFA method very similar to Hitachi's. A difference in emphasis is that Sony requires its designers to use it while sketching possible designs. The DFA score is one important way that alternate concepts are prioritized during this conceptual stage.

Toyota uses no formal DFA and asks quite seriously why anyone would need such a tool. Regarding well-publicized DFA activities at GM and Ford, Toyota designers ask if communication between designers and manufacturing engineers is really that weak at those companies.

These differences in approach and attitude indicate that the role of assembly analysis in product design is still evolving and capable of considerable improvement.

TYPICAL APPLICATIONS OF COMPUTERS IN DESIGN

In general, U.S. computers, both mainframes and workstations, and U.S. software dominate in Japan. Due to space limitations in offices, Japanese laptop computers are seen everywhere. Except for a few programs, nearly all commercial software is from the United States.

Specific applications of computers in design were much as one would expect. What is sometimes surprising is the depth of penetration of networked computerization at some companies (3,000 workstations, 1,000 Macintoshes, etc.), the degree of integration of many design steps in one computer system, and the commitment to growing their own capability internally and through joint ventures with software houses. In design, most companies visited are paperless or nearly so. However, paper is still valuable: no screen is as big as E-size paper, and huge drawings are commonly seen covering tables surrounded by conferring engineers. The factory floor people still want paper because it survives, can be marked up, and can be met over.

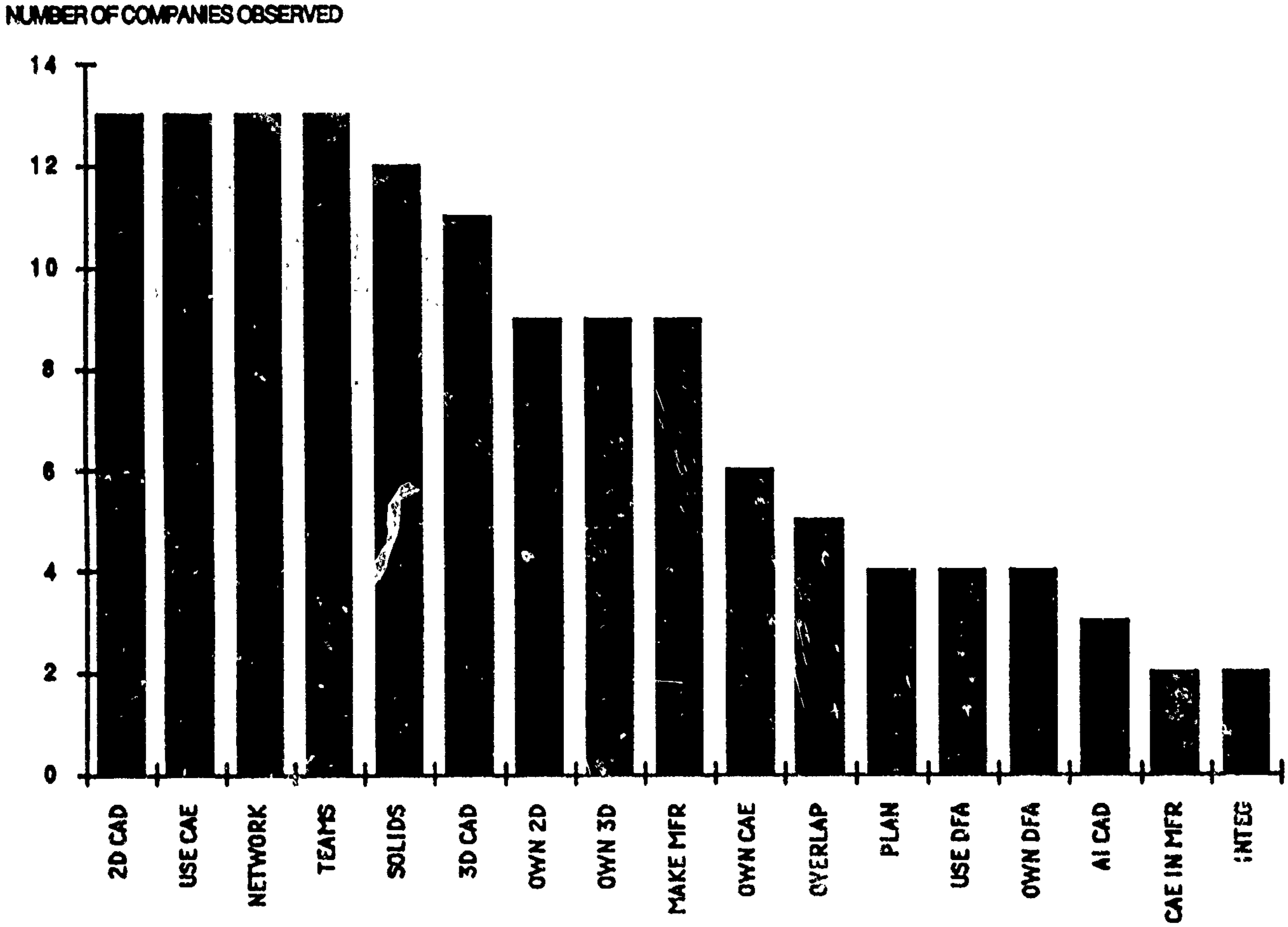
Figure 1 is a summary of design and product realizations actually observed at 13 companies visited.

The data in Figure 1 were sorted and cross plotted and appear in Figure 2. Companies are arranged across the top, sorted left to right by decreasing number of the computer technologies observed at each company during my visits. The technologies listed in Figure 1 are arranged down the left side, sorted top to bottom in decreasing number of how many companies they were observed at. An entry of "1" means that the technology was observed at the company. A "0" means it was not observed.

The "data" behind this plot are not particularly sound statistically since they represent what was observed. Especially at a large company, something not observed is just that and is not necessarily missing. Nonetheless, the "data" are interesting and suggestive. Sorting the technologies by their commonness across the companies shows that some technologies are very common, and the ones that are do not surprise us. Sorting the companies by how many technologies they have undertaken shows which companies are the most aggressive and advanced. Comparing these two kinds of data by cross plotting the sorted lists allows us to determine if companies have built up their computer design capabilities from the common to the rare or whether companies can jump in at any level in the hierarchy.

The ability to draw the diagonal line and contain most of the "1"s above and "0"s below indicates that computer technologies in design are accumulated and represent a long-term company effort to build capability, understanding, and infrastructure. It argues against computers being commodities. If it were possible just to buy computers and be able to "play with the big boys," then one would see "1"s all over Figure 2.

TECHNOLOGIES IN USE



Notes:

2D CAD	=	essentially all engineers have access to 2D CAD and few or no paper drawings are made except as informational output
USE CAE	=	the company uses some CAE in design
NETWORK	=	the engineers' workstations or terminals are networked together
TEAMS	=	the company uses cross-functional design teams
SOLIDS	=	solid modelers are in at least limited use
3D CAD	=	3D modelers (solids, wireframe, or surface) are in use
OWN 2D	=	company uses 2D CAD software it wrote
OWN 3D	=	company uses 3D CAD software it wrote
MAKE MFR	=	company makes key manufacturing equipment it uses
OWN CAE	=	company uses CAE software it wrote
OVERLAP	=	overlapping tasks design methodology is used
PLAN	=	company has a long-range plan for development of advanced CAD and design methods
USE DFA	=	company uses a formal DFA methodology
OWN DFA	=	company developed the DFA methodology itself
AI CAD	=	artificial intelligence applications to design are in use or being developed
CAE IN MFR	=	CAE is used in design of processes (molds, press dies)
INTEG	=	the company has at least one integrated end-end CAD/CAE/CAM software system

Figure 1. Distribution of computer technologies in 13 companies visited.

	WIDE CAPABILITY						COMPANIES						LIMITED CAPABILITY
COMMON	1	1	1	1	1	1	1	1	1	1	1	1	1
TECHNOLOGIES	1	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	0
	1	1	1	1	1	1	1	1	1	1	1	0	0
CAD/CAM/CAE	1	1	1	1	1	1	1	1	1	0	0	0	0
TECHNOLOGIES	1	1	1	1	1	1	1	1	1	0	0	0	0
	1	1	1	1	1	1	1	0	1	0	0	0	1
	0	1	1	1	1	0	1	1	0	0	0	0	0
	1	1	1	1	0	0	0	1	0	0	0	0	0
	1	1	1	0	0	0	0	0	0	1	0	0	0
	1	0	0	1	1	1	0	0	0	0	0	0	0
	1	0	0	1	1	1	0	0	0	0	0	0	0
	1	0	1	0	1	0	0	0	0	0	0	0	0
RARE	1	1	0	0	0	0	0	0	0	0	0	0	0
TECHNOLOGIES	0	1	1	0	0	0	0	0	0	0	0	0	0

Figure 2. Cross plot of companies versus technologies.

The interesting entries are the occasional "1"s that appear below the diagonal line. These indicate a company with limited capabilities that nonetheless is embarking on a technology that, in general, only much more capable companies have undertaken. Two of these are IHI, which has a definite long-range plan to integrate its computer design capabilities, and Mazak, which is world famous for using its own products in its unmanned, nonstop production lines.

A separate graph, not reproduced here, shows that there is a strong though imperfect correlation between company size and the number of technologies observed. This is also not surprising and indicates that smaller companies need help if they are to gain enough capability to serve as qualified suppliers to the large ones.

CAD

CAD is naturally used by all companies visited for ordinary drafting in two dimensions. Obvious 3D applications like layout and interference checking have been mentioned above. However, most companies check interferences by eyeball inspection of 3D wireframe or 2D cross-section drawings. Few use solid models for this purpose.

The most interesting computer applications are those in which the external appearance of a product can be so realistically represented that physical prototypes are not needed. Examples include Toyota's work on cars and Sony's on videocameras, but there are many. Toyota's goes beyond anything commercially available since it contains models of how its paints reflect light under different light and weather conditions in different cities in the world. Toyota has gone to great lengths in its home-grown surface modeling software to guarantee that the designers can easily manipulate the surfaces (always difficult in past methods) and can evaluate them by methods they are familiar with, such as simulating reflections of fluorescent tube lights.

Toyota and Nissan both can simulate how a car interior looks; at Nissan the display is in stereo. The driver's field of view and windshield wiper clear areas (both subject to government regulation) can also be simulated. At Toyota, integrated CAD/CAM is used to design car interiors as well as exteriors, including use of numerical control (NC) machining to cut out full-size clay models of dashboards and shift lever consoles.

CAM

All the obvious applications are represented here, too. The main one is creation of NC cutter paths directly from CAD data. However, some companies complained that their commercial software does not support this well for sculptured surfaces. Sometimes there are errors converting the data from one form to another. In other cases, the surfaces contain unwanted undulations. Toyota and Nissan do not have surface undulation problems but may have some data conversion glitches.

Other commercially available applications in wide use are mold flow simulations and some kinds of process planning. The Australian mold package called Moldflow is popular. Most companies seem to use SDRC's solid modeler as the front end for most CAM and CAE applications since SDRC resells a wide range of third-party software of this type and has taken care of the data conversion process.

CAE

Common applications in this category include FEM for stress, vibration, and heat flow problems, plus extensions thereof for complex turbulent flow studies. Commercial applications in use include NASTRAN, MARC, ADINA, and PAMCRASH (vehicle crash simulation). ADAMS is a kinematic simulator that is almost 20 years old but has recently come into wide use after SDRC attached it to its solid modeler. I was shown interesting simulations of how a washing machine rocks when the load is unbalanced, how a vacuum cleaner would track on its casters, and how a crane would react while swinging a heavy load.

Ambitious fluid flow simulations are used on supercomputers to evaluate exterior car designs for drag and to see if manifolds and injectors provide uniform distribution of fuel particles. Curiously, in spite of the progress made reducing the noise of products, no one admitted having CAE for noise evaluation. Structural vibration and rotor dynamics were often used as proxies for machinery noise studies, but fluid noise is not being simulated. One interesting simulation was of active noise suppression of air conditioner noise. Spectral analysis is involved, I think, but not fluid turbulence.

Preparation of FEM data has become a major bottleneck for everyone. Checking packed products for interference between parts, collision between moving parts, and access for parts and tools during assembly is becoming impossible to do without computers or costly prototypes, and huge data requirements make it hard to do by computer. Available research results that would speed up the process (octrees, for example) have apparently not been applied.

Except for some limited Monte Carlo methods, no one has software for evaluating tolerances or predicting fitup of nonperfect geometries. The IBM Tokyo Research Laboratory plans to start such research, and some is underway at the University of Tokyo. No one agrees as to whether a statistical approach should be taken or a deterministic one. Statistical approaches sacrifice some accuracy in the highest precision studies, but deterministic approaches are threatened by combinatoric explosion.

Several companies perform failure modes and effects analyses (FMEA) on their products and one does so on manufacturing equipment, but there are apparently no computer tools for doing so as part of the design process. (Toyota painfully recorded the causes of robot failures for several years and, with cooperation from its two main robot vendors, succeeded in raising the mean time between failures from 3,000 hours to 30,000 hours. News of this has spread throughout Japan and all robot manufacturers are raising their products to this standard. Motorola conducted a similar study of its Seiko robots but I do not know any statistics.)

Several companies acknowledge interest in design of human interfaces and one has some expert system work underway. Examples include how to position foot pedals and hand grips in cars and crane cabs.

RESEARCH NEEDS AND CAD IMPROVEMENTS IDENTIFIED FROM COMPANY VISITS

The following list comprises both what companies specifically asked for plus what I think they would use if it were available, based on what they said, complained about, reacted to, or implied. Several companies have launched improvements to their present capabilities but would not discuss them with me.

Conventional CAD

In this category are simply enhancements to existing capabilities that may require considerable effort.

Better User Interfaces to 3D Design Systems. Designers are trained on 2D systems and have a hard time adjusting to 3D. No really natural user interface to 3D solid modeling via a 2D screen is in use. Even for skilled operators, construction of a complex 3D model takes a long time. The mechanical designers rightly argue that current surface modelers were designed for cosmetic exterior design of cars and cameras and are not suitable for mechanical parts. Exterior surfaces are, in fact, quite simple and the parts contain few features and have no "inside." Mechanical parts have substantial insides that contain a lot of detail, plus many complex features. This problem appears to be a major blockage to further penetration of solid modeling in Japan. Several companies felt that feature-based design might provide an avenue for attracting mechanical designers to 3D.

Common Databases and Data Conversion. Everyone knows that current computing is a Babel of different languages, data conventions, and conversion protocols. It is a dirty problem, but it seriously stands in the way of rapid transfer of complex models from one CAD or CAE application to another. This, in turn, stands in the way of further integration of individual "islands of design automation" into complete design systems.

Automatic Data Preparation for CAE. The case cited most frequently is preprocessing of FEM data sets. These

are becoming more and more complex. Checking for errors and reasonableness can take a long time. One company cited a month as an example.

Advanced CAD

In this category are capabilities that are not available in any commercial CAD system, but creating them may be a near-term proposition, since one can imagine what means and information could be mustered.

Practical Kinds of Feature-Based Design. Providing catalog information, routine engineering calculations (such as how to design bearing seats or choose fasteners), and national and international standards (such as standard fit classes) should be relatively easy to implement. Ready-made geometry backed up by parameterized models would provide a natural interface. The necessary calculations for bearing preload and life, for example, could also be stored for easy access. It would be a start on changing CAD from a "draftsman's interface" to an "engineer's interface." A little more challenging would be constraint-based rules such as enforcement of safety factors. Since Japanese designers are in most cases university graduates, this kind of CAD might be well received.

Commercial U.S. software that offers or offered similar capabilities is that of Cognition and ICAD. Neither company seems to have made an impact in Japan.

Geometric Dimensioning and Tolerancing. This was discussed above.

Data Archiving and Retrieval of Past Designs. Some of this is being done now. It is unlikely that advanced data retrieval methods are being used, however To do so would require developing ways of classifying designs, a decidedly nontrivial task that no one here is working on Only rudimentary library search methods were seen in regular use.

Cost Feedback to Designers. It has been said that most designers do not know the cost impact of what they design. Presenting such feedback requires cost analyses of processes plus ways of analyzing the design to determine its cost components. Determining process costs would require doing some preliminary process planning. Materials costs would require a straightforward database. Vendor costs would require more than a database since estimates of negotiation results, discounts, shifting competition, and currency exchange rates would be needed.

Broad-Based CAD That Supports Full-Scale Concurrent Engineering

"Experienced Designs." This interesting term was used by a researcher at a company to mean a feature-based data file of previous designs that included proven process plans, statistical quality control results, process times and costs, customer feedback, and so on. That is, the data would represent actual experience, not just plans. This would be of more than historical interest if a way were available to extrapolate the experience in the database as the designer altered the design to suit a new requirement.

DFM and DFA Advice to Designers. As mentioned above, companies want more than just design critics in their CAD systems. They want corrective advice. Providing this will likely require deep knowledge to be represented, although near-term implementations of some valuable kinds of feedback and advice could be easier. For example, a tolerance stackup analysis could be followed by advice on which elements in the chain contribute the most to the final error. The required size of a compensatory chamfer could readily be calculated. The opportunities for part consolidation could be identified based on kinds of material and joints between adjacent parts.

It will be much more difficult to provide advice on whether a particular assembly action is "easy" or not. At the moment, companies rely on experienced people who usually do not use hard criteria to make their judgments. No one tries to predict whether a particular assembly task design would cause fatigue or carpal tunnel syndrome, or how hard it would be to retrieve a dropped part. Some companies use simulation to predict robot cycle time but none feed this information back to the designer in the hope of finding a design that will yield a shorter cycle.

Ways to Use Partial Information. The essence of the overlapping tasks method is to launch designs based on partial information and assume values for information that is delayed. Companies want ways to categorize this information according to how important it is, when it is needed, and how the impact varies depending on how much the delayed information, once it arrives, deviates from what was assumed. Among the possible difficulties are wasting time in extra design iterations or creating grounds for product liability if incorrect assumptions are not eliminated before the design is released. Past data, experienced designs, sophisticated change notification methods, and standardized designs will likely be utilized to solve this problem.

How to Automate in the Face of Diversity and Design Change. Only Nippondenso appears to have given deep thought to this problem. Most companies use people where more flexibility is needed than current automation can provide. Most researchers try to make smarter automation. However, Nippondenso has merely applied

a form of sophisticated planning to such designs as the alternators and radiators. Nippondenso has extended the range of types or sizes it can handle in one automated system, but it is still totally restricted to the factors it planned and designed for. One or two dimensions can be varied within a fixed range, for example. No major product configuration change can be accommodated without the same equipment redesigns that any other company would face.

This problem is one of many I could cite for which even existing research efforts would be insufficient. Despite the apparent difficulty, however, companies badly need this problem solved.

MAIN THRUSTS IN UNIVERSITY RESEARCH

I saw a great deal of very innovative university research in design during my stay. Some projects were motivated by discussions with industry while others were clearly the brain-children of the researchers. Topics covered below are:

- Knowledge Representation - qualitative reasoning
- Direct Support for Designers - feature-based design, partial designs, and conversion of requirements into realizations
- Management Methods and Best Practices

Knowledge Representation

Generally, there is a lot of artificial intelligence work going on in mechanical engineering. Most of what I saw is at the University of Tokyo, but I also saw some at Kyoto University.

University of Tokyo. In Prof. Tetsuo Tomiyama's laboratory, the emphasis is on creating a "meta-model" of engineering. A meta-model can contain submodels of typical engineering and can represent various "aspects" of a design, such as the kinematic, thermal, or structural portions of the behavior of something.

These meta-models are being constructed using qualitative physics, which provides symbolic representations of what are normally modeled by equations or logical constructions. Facts about nature (if a body with positive velocity experiences positive force, the velocity will increase) and about logical state changes in a system (if the wire melts, the coil will stop conducting electricity) can be expressed. These are stored in a library. A designer can construct a model of a physical system by describing geometry roughly and placing library objects in relation to each other. The computer augments this basic model with a number of side effects (the engineer describes the coil but the computer describes the heating effect that might lead to melting). When the model is complete, the computer can determine that the motor will turn continuously between some discrete angular states if it starts in the right state.

Two applications of this idea other than analyzing designs are underway. One is "self-maintenance machines" and the other is simulation of designers' actions while designing.

The self-maintenance machine currently under study is a photocopier with sensors for copy density and other quality issues. The computer has a network model of causes and effects input by the user that tells what happens to each visible variable (copy density) as each internal variable (lamp brightness, lamp voltage) varies up or down. From this the computer can calculate a failure modes and effects analysis for certain failures. When a failure is observed, the computer reasons backwards to a set of possible causes and reasons forwards to determine a set of possible remedies. The remedy with the fewest side effects is chosen.

Simulation of designers' actions is less well developed. It employs several logical techniques to follow a protocol recorded from a real designer and can imitate his reasoning from a first concept to the discovery that the concept will not work, to trying a second concept, and so on. However, this system has no physical knowledge and apparently only simulates the logic. Future work will connect this work with the meta-models more directly.

Qualitative physics of the kind used in the self-maintenance machine has been pursued at length by chemical engineers for at least 5 years. The approach is rather good at imitating how people think and can store a great deal of partly structured information. Unlike equation models, this method can deal easily with logical state changes. However, it takes a lot of work to describe even a simple system, and the user contributes most of the real knowledge about how things relate to each other. Therefore, it remains to be seen how or when this approach will be able to do better than people. The promise is in the automatic generation of the side effects, giving the ability to tell the designer something he overlooked or might not have expected.

Kyoto University. At the laboratory of Prof. Norio Okino, work is going on to create a hierarchical representation of physical things in the world of manufacturing. The approach is quite object oriented and consists of replicating an object called a modelon at every level. A modelon has a common memory and a set of processes describing its behavior connected to the memory. It also contains subprocesses that are modelons as well with the same general structure. In software, each modelon is a Unix process.

Modelons operate independently of each other and seek to answer requests for action from higher levels while sending requests laterally and to lower levels. There is not much structure to

these interactions. The student demonstrating one system did not know the terms "forward chaining" and "backward chaining." The lack of interaction structure and the independent operation of each modelon are deliberate; Prof. Okino calls the approach "bionic manufacturing." The long-term objective is to create manufacturing systems that are self-modifying and self-governing regardless of how complex they become.

The applications demonstrated included robot grasp planning and hidden line removal. In the former, the robot, the object to be grasped, and the gripper each are separate modelons seeking to find graspable faces. In the hidden line removal problem, each modelon is a solid that intersects the others, and the submodelons tell lines how to decide if and how much they are hidden.

Direct Support for Designers

At Prof. Fumihiko Kimura's laboratory at the University of Tokyo, several varieties of CAD are being pursued. Some of their recent work on solid modeling and constraint-based design has been overtaken by new releases in the commercial world, such as SDRC's Level VI, but other work is farther ahead and will yield practical results soon. These include methods for predicting configurations of assembled parts, taking tolerances and imperfect geometry into account, and design of sheet metal parts where only part of the design is given explicitly by the designer.

The sheet metal design project is interesting because it attacks an aspect of design mentioned above, namely, operating with partial information. In this case, flat sheet metal parts must obey requirements, such as having holes in certain places. However, portions of the part, especially of the perimeter, are unspecified in detail. It is known that other parts will intrude at some places and that all the given holes and slots must be included within the part's boundary. The computer then suggests a perimeter shape, which the user can modify.

Another interesting area is called top-down design. This is similar in broad spirit to Prof. Tomiyama's work but is more focused, less general. The idea is to provide the designer with geometric features that have engineering knowledge attached to them. These features often come in pairs that operate together but normally belong to different parts (bearing and seat, screw and hole). The required knowledge is actually shared in the pair and ought not be separated out to the single parts. Some precalculations are also represented. For example, if the designer specifies the load on the shaft, the correct size bearing is recommended.

Prof. Kimura recognizes that the main need is to transform CAD from something that produces a model of a drawing to something that produces a model of a product. The exact composition of a "product model" is unclear at this point, but it obviously needs information of both an engineering and a business nature. How many units will be sold in Brazil 2 years from now must be known to the product and process engineers for a variety of reasons. The international STEP/PDES effort is a step in this direction.

At the moment, no top-down approach for creating such models exists. The current approaches are via features. Stringing features together is distinctly bottom-up and could become a shapeless mass unless some top-down structuring is applied first. Yet the top-down structure must be flexible and capable of being revised by the designer without destroying the lower levels. Early attempts at this will likely produce methods that impose a design methodology on the designer. If it is the least bit restrictive or awkward, it will be rejected immediately.

Management Methods

Prof. Fujimoto's research on design practices in the world auto industry has been discussed above. Generally, this follows a common business school research paradigm called "best practices." The goal of such research is not to work out new inventory control algorithms or accounting formulae but to determine what the best companies do and how it differs from what less-capable companies do. The research approach involves interviews, questionnaires, and statistical analyses of questionnaire results. One may find, for example, that companies with high model mix, JIT production methods, and democratic management methods are more likely to have high quality and low cost than companies with other management and operating practices.

Prof. Fujimoto is about to launch a new study on how companies deploy assembly automation. Another project will study design and automation in auto companies, semiconductor manufacturers, and precision instrument makers. Each is a rather different industry with different production rates, quality requirements, and processes. In our discussions, I noted that differences in automation penetration in these industries do not depend as much on the attitude of managers as they do on production rate and the degree to which the processes are understood.

The questionnaire method has revealed some penetrating information that was not widely appreciated outside of the companies themselves. However, it can be difficult to make hard statistical analyses because the method does not admit the usual checks and balances, namely, control sets and double-blind techniques.

Role of the IMS and Other Government Activities

The IMS was originally proposed by Prof. Hiroyuki Yoshikawa of the

University of Tokyo, a pioneer thinker in product realization. While the current state of the IMS is beyond the scope of this report, it is important to note that the Japanese are not waiting for international consensus and are beginning to fund exploratory projects. However the IMS proceeds, it or its derivatives will improve communication between companies and top level researchers in product realization. The result will be new and more powerful design technologies built on the accumulated experience of the companies and the intellectual power of the universities. Conversion of the IMS results into usable software will be an interesting and instructive exercise because, as discussed above, some companies extensively develop their own design software while others buy it almost exclusively from the United States. A successful IMS will probably cut Japan free of further dependence on the United States for this vital ingredient of manufacturing excellence and at the same time solve a serious long-term problem.

ARE JAPANESE COMPANIES AND UNIVERSITIES DIFFERENT FROM U.S. OR EUROPEAN ONES?

The major manufacturing companies of Japan, as discussed above, see themselves as responsible for the main skills of product realization. The resources are technology and people, and major investments have been made in both. European companies are similar, and in Germany, both the government and industry invest heavily in human resources through national apprentice programs.

Japan's smaller companies can keep up in technology with their bigger brothers (usually customers) because both the big companies and the government help. Big companies provide training and sell technology. Prefectural governments maintain large field services for training small companies on new manufacturing technology and software. America's Agricultural Extension Service operates the same way for the benefit of farmers but no corresponding program exists in manufacturing.

In the United States, most manufacturing companies focus on selected aspects of manufacturing and leave the rest to vendors. GM had R&D programs in both robots and sculptured surface software in the early 1960s but made business decisions to stop both. Today, no supplier of machine tools or robots in the United States has the resources of Toyota or Nippondenso to apply to R&D of its products.

In Europe, large companies (VW, Bosch, Siemens, Aerospatiale) tend to be more like the Japanese ones in the sense that they develop manufacturing and CAD technology internally. German industry has made extensive use of university laboratories in cases where Japan and the United States would use vendors. Examples are high technology deliverable end-items like robot microcomputer controllers and flexible manufacturing system (FMS) scheduling software.

Japanese companies tend to take time to mold their employees to their liking. This is facilitated by the lack of professional concentration in Japanese engineering education. Classes at the bachelors level are general and do not convey much deep knowledge. The curriculum is wide ranging and contains no required subjects. Students in "mechanical engineering" take subjects in software, information theory, image processing, and robotics. They graduate without seeing themselves as strongly mechanical in outlook or commitment. One company with a low-tech, mechanical image, needing electronics engineers for its modern products, hired the mechanical engineers who showed up and retrained them in electronics.

It is also easy to cross train such engineers in design and manufacturing. This gives them what is called "universal experience." At Nissan, several key people planning and managing new CAD spent 5 to 15 years in manufacturing engineering or product design first. Japanese university research in robotics has tended to be aloof from industry, while that in CAD/CAM has until recently focused on traditional topics like metal cutting. The national universities, facing budget cuts from the Ministry of Education, have either lost students and staff to better-funded private universities or have modernized their curricula and strengthened contacts with industry. As a result, more vibrant and relevant CAD/CAM/CAE research is going on. The funding mechanism often is consortia made up of modest contributions from many companies. The more active professors are on the road visiting companies almost weekly, it seems. These factors guarantee that future research will be relevant.

German universities have long had close collaborations with local industry and do much research that we would regard as development or even applications engineering. This has not hurt German industry to any visible degree and has not kept German research from being widely respected.

U.S. universities have obtained most of their research funds from the government for the last 40 years and did not do much in manufacturing from the late 1950s until the past 15 years. Government agencies still have trouble understanding why research in design and manufacturing is either relevant or likely to be productive. Industry does not see enough that is relevant in current university research in manufacturing and does not fund it very heavily. The decline in military R&D and a trend toward closer university-industry ties could change this quickly.

WHAT WILL HAPPEN NEXT

I believe that we are on the threshold of a major increase in the capability of CAD/CAM/CAE, and my Japanese academic contacts agree. The stage has been set for implementation of first-level feature-based design. Once a few applications of this come into use, people will see the real potential and demand will grow rapidly. There are two elements to this potential: mustering of engineering knowledge and redefinition of the user-computer interface.

Routine knowledge will be the first to be captured, such as catalog information discussed above. Second will be procedures that experts follow, initially without any deep background other than mimicry, later with some logic branching and case-based methods. The major output from such computer applications that will differentiate them from all past applications will be the first data models of products, in contrast to today's models of the drawing on the computer screen.

These data models will provide significant new capabilities linking product function design to fabrication and assembly process design. Even a little data on product topology defined by feature-connections have proven powerful in permitting complex assembly process planning to be automated (Ref 5), for example. The right kind of data structure definitions will make it relatively easy to create many new and significant tools of this kind; applications will snowball. Providing users with the ability to create these applications will be especially powerful.

The redefined user-computer interface will make computers routinely used for complex engineering, in contrast to today's use for complex drawing. The kinds of information that can be linked will broaden to include some basic process engineering at the functional design level.

However, process engineering in general still takes second place to function engineering on industry's priority list. The potential for redressing this exists in several areas, but neither the companies nor the universities have pressed the issue hard enough. The companies all offer the same explanation, namely, that they have experienced people who can do that now. But they could have said that 20 years ago about ordinary CAD. In other words, the potential is huge, especially if it is joined to functional design to produce true concurrent engineering. Since many Japanese companies have newly launched projects to improve design methods on top of their current capabilities, it is likely that application of computers in these projects will increase and will be extremely effective.

Design process management, information flow analysis, and design process improvement are just starting to be recognized as subjects for research and technology. Rapid progress can be expected in these areas because the main issues are not hard to model and several existing approaches are waiting to be applied. More generally, the potential for joining engineering and management methods in unified computer models of design is large.

Geometric dimensioning and tolerancing is one of many functional and process design areas that resists major improvement because there exist as yet no firm mathematical models of many of the geometric variations that have been used loosely in the past. The advent of solid models brought these shortcomings to light and international committees are working on them, but a complete model may take some years to create.

The most long range research involves trying to capture deep knowledge in new ways. We already have very sophisticated mathematical models of some phenomena that permit impressive simulations, such as crash and skid tests of cars. It will be a long time before current research on qualitative methods can challenge existing models. In the meantime, people will always be able to do better, faster.

The result is that researchers in many areas will have to choose what roles they think people and computers, respectively, should have in future design systems. One approach is to try to capture deep knowledge so that the computer can in many ways become the designer. The other is to acknowledge that such capture may be impossible for a variety of reasons. Then one would focus on aiding the designer in doing things that he/she could do in principle but should not waste time on or may not do accurately enough. Examples include sorting, matching, enumerating, searching, optimizing, maintaining constraints and enforcing rules, drawing evocative pictures, and otherwise empowering people to apply their deep knowledge.

The advantage of the latter approach is that practically every research result will be immediately applicable, and verification of the underlying methodology appears practical. Companies will thus tend to trust and adopt the methods.

ACKNOWLEDGMENTS

I would like to thank the following organizations and people for their help, support, and hospitality. They worked hard for me and made my stay enjoyable and educational:

Office of Naval Research:

Dr. Arthur Diness
CDR John Sheridan
Dr. Donald Polk
Ms. Roberta Perry

Charles Stark Draper Laboratory:

Dr. David Burke
Mr. Richard Riley
Mr. John Barry
Ms. Judith Repetti

ONR Far East Office:

Dr. Sachio Yamamoto
Mr. Frank Nagashima
Mrs. Sandy Kawano
Ms. Mayumi Shirakawa
Mr. Ronald Wright

University of Tokyo:

Prof. Fumihiko Kimura
Prof. Hirochika Inoue

Companies:

Toyota (Mr. Yasuhiko Kuranaga)
Nissan (Mr. Jun-ichi Kobayashi)
Mazda (Mr. Masahiro Matsumoto)
IHI (Mr. Hiromichi Nakajima)
Hitachi (Mr. Michio Takahashi)
Sony (Mr. Tohru Fujimori)
Nippondenso (Mr. Koichi Fukaya)
Seiko-Epson (Mr. Akio Mitsuishi)
Ricoh (Mr. Yukihiro Ageishi)
Yamazaki Mazak
(Mr. Hiroshi Awane)
IBM Japan (Mr. Chihiro Sawada)
Nikon (Mr. Hideaki Okamoto)
Hitachi Construction Machinery Co.
(Dr. Kozo Ono)
Fujitsu Ltd. (Mr. Sadao Fujii)
Hitachi Seiki Co. Ltd.
(Mr. Kazutaka Kubota)

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INTELLIGENT MATERIALS SYSTEMS AND MATERIALS SCIENCE RESEARCH IN AUSTRALIA

The concept of "smart/intelligent" materials systems is receiving increasing attention by researchers worldwide. This article summarizes recent developments reported at the Army Research Office Far East cosponsored Asia-Pacific Workshop on Intelligent Materials Systems and Structures, held at the University of Wollongong in August 1991, and reviews some of the research activities in materials science at various universities and government and industrial laboratories in Sydney and Melbourne.

by Iqbal Ahmad

REVIEW OF THE WORKSHOP

Introduction

Since the first Army Research Office (ARO) supported workshop on Smart Materials, Structures, and Mathematical Issues, held at VPI in 1988, there have been a number of workshops and symposia on the subject in various countries. For example, an international workshop was held in Japan in 1989, which was followed by a U.S.-Japan workshop on Smart/Intelligent Materials and Structures held in Hawaii in March 1990 [see the article by I. Ahmad, "U.S.-Japan Workshop on Smart/Intelligent Materials and Systems," *Scientific Information Bulletin* 15(4), 67-75 (1990)]. The Proceedings of the latter were published by Technomic Press in 1991. In fact, there is now a worldwide interest in the concept of "smart" or "intelligent" materials and structures. In nearly every country with advanced research activities in materials science and engineering, it is being discussed in various national and international forums. The most recent workshop, which is the subject of this review, was held at the University of Wollongong, Australia, from 19-21 August 1991.

The main objective of this workshop was to explore the potential of this emerging technology in the context of the research, development, and testing (RD&T) capabilities of Australia. It was cosponsored by ARO Far East (AROFE) and a number of Australian organizations including the New Materials and Technology Committee, Monsanto, BHP, the Royal Australian Chemical Institute, Illawara Technology Corporation, and the University of Wollongong. There were about 40 participants, all from Australia except for 3 from Japan and 2 from the United States.

The deputy vice chancellor of the university, Professor G. Sutton, gave the welcome address. Then Professor Gordon Wallace, who was the chairman of the workshop and is the director of the University of Wollongong's Intelligent Polymer Research Laboratory, described the activities of his laboratory in the area of intelligent polymers. He stated that their interest was in the development of intelligent chemical systems based on unique groups of polymers that are inherently dynamic. The focus of their current research is on active membranes. Assuming them to be intelligent material systems, he identified the characteristics of an intelligent system to include sensing, transduction, and response. The motivation of developing the intelligent materials systems concept included not only the possibilities of discovering new materials but also new production processes and new material characterization techniques.

The Concept

Professor Craig Rogers of the Virginia Polytechnical Institute, in his keynote speech, stated that man had always used nature as a source of inspiration for design and engineering of the materials and structures needed by society. The development of the concept of intelligent materials and systems was essentially mimicking nature to produce lifelike functions of sensing, actuation, and control. Realizing that there was as yet no consensus of the scientific community on the definitions

of the terms "smart" and "intelligent," he gave his own version. He preferred to use the term "smart" for the materials and engineering systems and "intelligent" for the science aspect of the concept. He stated that in his opinion no monolith material was intrinsically intelligent. All intelligent materials in nature were systems, such as composites. He gave a number of examples of the smart/intelligent systems and structures that are being developed in the United States, as well as some of those that occur in nature. These systems are designed to adapt to the environment and represent the integration of the software with sensing and actuation.

Professor K. Takahashi of the Tokyo Institute of Technology spoke on the concept of intelligent materials and electronics. He reiterated what he had said in the previous two workshops about the definition of intelligent materials and stated that "intelligent materials" might be reasonably referred to as materials that possess characteristics similar to or exceeding those found in biomaterials.

Professor M. Aizawa of the Department of Bioengineering, Tokyo Institute of Technology, described an intelligent bimolecular material that incorporates three functional moieties, such as sensing, processing, and actuating functions, in a single molecule or that integrates these functional molecules in a collaborative supramolecular assembly. Since such molecules respond to specific information, resulting in an action of the actuating moiety, they have found a variety of applications in drug delivery systems. He used the example of calmodulin, which has covalently been conjugated with phosphodiesterase (PDE) as a model case of an intelligent bimolecular material. Calmodulin specifically binds the calcium ion, which changes its conformation, triggering PDE in its enzyme activity. The enzyme activity is modulated by calcium ions in solution through a conformational change, which indicates that the information was transmitted from the calmodulin to the PDE moieties. This example is one of the closest (in my opinion) to the realistic characteristics of a smart/intelligent supramolecule and shows that such molecules can manifest intrinsic characteristics of the smart/intelligent concept.

Some Intelligent Materials Systems

There were a number of papers from Australian institutions that identified various intelligent functions in biosystems. For example, Dr. Bruce A.M. Cornell of the Division of Food Processing, Commonwealth Scientific and Industrial Research Organization (CSIRO), North Rye, New South Wales, described a number of molecular systems that can be used in data storage, switching, sensing, and diagnostic devices. Molecular properties of biological membranes are his main research focus, and he discussed some of the conduction properties and applications of synthetic lipid bilayers and the membrane-associated ion channels.

Dr. M. Crossley of the Department of Organic Chemistry, University of Sydney, discussed molecular electronics, which involves a "molecular wire" enabling electron flow between functional components of the system. According to Crossley, porphyrin systems in which individual porphyrin rings are directly fused or bridged by coplanar aromatic systems should meet these criteria. He is also studying a series of tetra-azanthracene-linked porphyrins, which manifest many properties that may be applicable to the synthesis of molecular electronic devices.

Dr. G. Bell of the Sensory Research Center, CSIRO, reported his work on chemical sensors based on the combination of olfactory receptor molecules and conductive electroactive polymers for process control and safety.

Professor H. Green of the Department of Physics and Mathematical Physics, University of Adelaide, gave an interesting overview of the structure and function of some of the important components of the nervous system and the cortex of animals. He described some simplified models of realistic neural networks capable of parallel processing and highlighted the role of mathematical modeling in these activities.

New Applications of the Concept

On the more applied side, Professor Y. Osada of Ibaraki University, Mito, Japan, reported on the first model of an electrically driven artificial muscle possessing motility like that of a robobug. The system is based on a chemomechanical process driven by the electrokinetic molecular assembly reaction in a weakly cross-linked polymer gel of poly(2-acrylamido-2-methyl propane sulfonic acid (PAMPS). When 20-V dc voltage is applied through a pair of carbon electrodes (450 mm long by 10 mm wide separated by a distance of 20 mm) placed on the upper and bottom sides of the hydrogel, and altering the polarity with 1-second intervals, the gel walks forward by repeating the bending and stretching action. The velocity of walking of the looper is a function of the applied current and salt concentration of sodium sulphate and the molecular size of the alkyl chain of the surfactant used. The actuation mechanism involved is different from piezoelectric materials or shape memory alloys as it is based on water-swollen hydrogel and makes continuous or analogue type movement.

The theory of electric field driven switches was the topic of the presentation by Professor N. Hush of the University of Sydney, in which the possibility of employing weakly coupled symmetrical bistable molecules or ions that undergo configurational change under external perturbation in hypothetical

logic or memory circuits was discussed. Factors influencing memory time and switching rate for dynamic and static RAM operations were described in connection with the theoretical possibility of constructing logic gates with suitable molecular switch circuits.

Professor Unsworth, director of the Center of Materials Technology and the head of Department of Materials Science, described electronic devices and circuits fabricated in his laboratory from electroactive polymers, particularly those designed to protect sensitive financial information stored on microprocessors against "hardware hacking." Unsworth suggested these devices can be of value to protect software used in command, control, communications, and intelligence (C3I) operations.

U.S. Government Funded Projects

Professor Rogers, in his second presentation, reported on some of the projects in the area of smart structures funded by the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), the National Science Foundation (NSF), and some Department of Defense (DOD) agencies. One of the important points he made was that most of the researchers involved in developing smart structures in which piezoelectric materials, electrorheological fluids, or shape memory alloys are being used did not appreciate the magnitude of the force required by the actuating assembly to perform the job in real applications such as vibration control. He emphasized the need for new actuator materials with increased "authority."

I summarized the ongoing program on Smart Materials and Structures managed by ARO and also briefly described the scope of the following programs under the University Research Initiative (URI) that will be initiated in FY1992 (the managing agency is in parentheses).

- Foundation of Intelligent Systems (ARO)
- Interdisciplinary Research in Smart Materials, Structures, and Mathematics (ARO)
- Materials for Adaptive Structural Acoustic Control [Office of Naval Research (ONR)]
- Tactile Information Processing: Biological and Machine Object Recognition and Manipulation (ONR)

Conclusions of the Workshop

In the panel discussion at the end of the presentations, comments were made by the Australian Government and university representatives and the Japanese and U.S. participants pointing out that the topic of intelligent materials systems is of great future significance to materials science and industry. The United States and Japan have been quick to recognize this potential, but Australian involvement in this area is relatively new. Several questions such as establishing multidisciplinary research teams with a "critical mass" and how to fund research in this new area were raised. One of the government representatives indicated that there would be no new funds available from the government agencies. I suggested that some windows of opportunity, such as the Window on Science program of the Office of Naval Research Asian Office (ONRASIA) and the Exchange Visit program of ARO, which could lead to some collaborative research with U.S. scientists, were available. This was enthusiastically received and a number of questions were asked about the scope of activities of the international offices of ARO, ONR, and the Air Force Office of Scientific Research (AFOSR).

With respect to the most important areas in which research should be directed, in the context of the Australian scene, the consensus of the participants indicated biosensors, membranes, use of electroactive polymers for data storage and integrated circuits, controlled drug release systems, prosthetics, and molecular electronics and devices.

Considerable interest was expressed by some of the Australian participants in the ARO-supported URI program. I provided as much information as was available and then suggested that they contact the ARO program managers in the field.

RESEARCH PROGRAMS IN MATERIALS SCIENCE

General Comments

Australia is a large country (about the size of the United States) with a population of only about 17 million. It is rich in natural resources including minerals and energy. Traditionally, its economy has been based on the export of primary products including minerals, grains, wool, and other dairy products. It has a relatively small manufacturing sector, serving mainly its small population. Australia has a relatively high standard of living. To maintain it, it is essential to vitalize its manufacturing sector, for which the importance of R&D is well recognized. Considering the number of people in the country, the R&D base in science and technology is good. However, R&D is mainly funded by the Federal Government and to a much lesser extent by the State Governments, rather than by industry. At the same time the utilization of the results of these research activities by industry is very low, which is discouraging the research institutions. Nevertheless, it is slowly changing, under the new government policies to vigorously

promote R&D in areas important for the economy of the country. One of the major fields of science seen to be the key to Australia's industrial future is materials, of which advanced ceramics forms a prime sector. Consequently, most of the laboratories I visited are involved in R&D in ceramics and thin ceramic films.

In 1989-90 the Australian Government support for major programs in science amounted to $A2.4 billion, of which government research agencies received $A813 million. Most of the high tech ceramic research was in CSIRO, the Defense Science and Technology Organization (DSTO), and the Australian Nuclear Science and Technology Organization (ANSTO). To encourage industrial participation in research, an R&D tax concession is the major instrument used by the Government. The Australian Research Council (ARC) is a major arm of the government science policy that recommends funding to the universities. In 1990 the ARC allocated grants totalling $A66 million of which $A32 million went to five universities. One of the priority areas for these grants is materials science and mineral processing. The Offset Program established by the Government provides opportunities to obtain new technology and access to international markets. Where government purchase contracts made with overseas suppliers contain in excess of $A2.5 million worth of imported content, the overseas supplier is required to perform "offset activities" in Australia to a value of 30% of the value of the contract's imported content. These activities may include R&D and technology transfer. Special grants to enable Australian scientists to participate in international scientific research are administered by the International Science and Technology Advisory Committee (ISTAC), for which an allocation of $A2.35 million has been announced recently. Optoelectronic materials and technologies and advanced processing of materials for materials fabrication and manufacture are amongst the priority areas supported by these grants. Grants for industry R&D (GIRD) and new materials technology (NMT) are awarded annually to consortia consisting of both research institutions and industry in high tech materials science including surface engineering, optoelectronic materials and devices, high T_c superconductors, engineering polymers, biomaterials and devices, engineering ceramics and advanced structural and composite materials, and advanced processing of materials. Finally, a new government initiative announced in 1990 is the Cooperative Research Centers (CRC) program, which will fund up to 50 centers, with total government funding rising to $A100 million per annum by 1995. In addition, there are programs supported by the State Governments. Therefore, on the whole, there is no weakness in government policies of R&D promotion, particularly in materials science, which brightens the future of materials science and technology in Australia. However, at this time, one can find some very active groups conducting world class research, but there are a number of institutions where the level of research is only fair or weak.

Site Visits

At the University of New South Wales, Professor Dou is developing advanced techniques to fabricate and characterize high T_c wires, which have shown one of the highest J_c values. The work is being supported by an industrial consortium. An impressive facility for the deposition of diamond films and characterization of thin films of diamond and cubic boron nitride is headed by Professor McKenzie. He has established a modified arc-evaporation system to deposit thin, dense, and pore-free films of diamond and other inorganic phases. The conventional arc-evaporation techniques used extensively to apply wear-resistant coatings to machine tools has the problem of extensive distribution of microparticles, which limit the performance of the coatings. McKenzie filters out these particles using a magnetic plasma duct. The ions produced in the arc-evaporator are focussed into the plasma duct, which consists of a vacuum tube surrounded with magnetic solenoids. The electrons in the plasma are confined by the magnetic field. The resulting electric field is coupled with a positive potential applied to the duct that is sufficient to steer most of the ions around the duct. One can use this technique to deposit defect-free thin films of metals, alloys, nitrides, carbides, or carbon. McKenzie also collaborates with Japanese researchers M. Murakawa, S. Miyake, and S. Watanabe at the Nippon Institute of Technology on the characterization of cubic boron nitride (cBN) films. According to McKenzie, only the Japanese workers have been able to successfully prepare cBN films; there are no reports of production in the United States. These films were prepared by reactive ion plating from a boron evaporation source on a silicon substrate. To achieve good bonding with the substrate, apparently, a titanium interface layer, was introduced. McKenzie is also collaborating with Dr. Amaratunga of the Engineering Department of Cambridge University, United Kingdom, on the deposition of amorphous diamond-silicon semiconductor heterojunctions.

Professor Y.-X. Mai at the Engineering Department of the University of Sydney is well recognized for his work on the fracture mechanics related to the modeling of the indentation technique for determining the fracture toughness of ceramics. He is also contributing regularly in the area of micromechanics of interfaces in ceramic composites.

At the invitation of Dr. Michael Swain, I visited the CSIRO Applied Physics Laboratory, which is also the

site of the National Measurement Laboratory, which is very well equipped with state-of-the-art instrumentation for precise measurement of physical properties of materials as well as developing standards. There is considerable activity on the development of new and improved instruments. For example, an ultramicro indentation system for investigating plastic and elastic properties of coatings and near-surface materials has been developed and is being marketed internationally. The laboratory is also involved in advanced development of electronic materials and devices. Swain showed me the facilities for reactive sputtering and ion plating.

In Melbourne I visited another institute of CSIRO known as the Institute of Industrial Technology. It may be pointed out here that CSIRO is one of the largest and diverse institutions in the world. It has a staff of 7,000 including 2,500 scientists working in some 100 laboratories and field stations throughout Australia. The major objectives of CSIRO include:

- Carry out strategic research that can be applied by Australian industry or government for the community benefit.

- Collaborate with other institutions and industry to strengthen the research effort and ensure its transfer and application.

- Lead and promote an expanded science and technology effort in Australia.

At the Institute of Industrial Technology, major programs include ceramic powders such as those of zirconia, glasses, carbon fibers, ceramic composites, high T_c superconducting materials, fuel cells, etc. The significant contributions of this institution include the development of processes for the manufacture of zirconia powders and the transformation toughening of ceramics. Zirconia powders, partially stabilized zirconia, and zirconium chemicals are being manufactured by Imperial Chemical Industries (ICI) subsidiaries Z-Tech Pty Ltd. and Nilcra Ceramics Pty Ltd., which are located very close to the CSIRO laboratory. At the Polymer Division, Dr. Peter Wailes and his associates discussed with me some of the ongoing projects on the special resins that were being developed for use in the ceramic fiber reinforced polymer composites. This group is also collaborating with the Institute of Industrial Technology, where a pitch-based carbon fiber is being developed at the pilot plant scale.

Monash University, which is located in the vicinity of the CSIRO laboratories, is essentially an undergraduate engineering school. Its Materials Science Department is headed by Professor Paul Rossiter, who has been successful in establishing a Center for Advanced Materials Technology, which serves as a service laboratory to members of a consortium that includes four universities, one DSTO laboratory, and some industrial concerns. The center aims to provide an Australian focus for the generation of advanced aerospace technologies that will foster the development of an efficient and globally competitive aerospace industry.

Another research institution in the area is the BHP Research Center. BHP is one of the largest industrial complexes in Australia. With a capacity of 7 million tons a year, BHP is Australia's major steel producer and is one of the leaders in continuous casting technology. BHP's Melbourne Research Laboratory, also known as MRL, supports the steel group's activities with R&D in steel processing and product development. Major programs involve the development of models for the prediction and control of solidification behavior in slab, bloom, and strip castings and the pilot scale simulation of continuous casting for optimizing conditions for the production of high quality steel. The laboratories are equipped with the necessary equipment for studying experimental alloy melting, casting, and thermomechanical processing and characterizing the composition and metallurgical and crystallographic structure. The structural engineering group studies the behavior of steel and composite structural elements for the development of design codes for composite slabs and other elements. Research is also in progress on other advanced structural materials including high molecular weight polyethylenes, sialon, silicon carbide, whisker-reinforced ceramics, and cutting tools. Another department is engaged in the ground radar probing program of sensing mineral deposits. BHP is also a large producer of oil and gas. Therefore, research programs are addressed at supporting these activities, as well as developing alternate fuels, including synfuel, coal gasification, and catalysis.

Dr. Maurice de Morton was the host at the Materials Research Laboratory of DSTO in Melbourne. I was briefed by the program managers on the progress of their projects since I visited them in August 1990. Noteworthy was the work on the stirling engine, which the MRL scientists are evaluating for their submarine program. A full-scale engine has been imported from Europe and is being evaluated for fuel efficiency and other engine characteristics. At a lunch meeting, Morton discussed administrative matters, including the Australian Government's plans to reduce manpower and funding at the laboratories. He stated that there was pressure on them to bring in funds from outside and to establish collaborative R&D programs with industry.

At the University of Melbourne, I visited the Microanalytical Research Center, which has been recently equipped with high resolution electron microscopes and other surface characterization instrumentation and analysis devices. One of the unique pieces of equipment brought to my attention was

the scanning proton microprobe, which has been developed and is being marketed by this laboratory. It is essentially a charged particle accelerator capable of detecting all elements, with low background and high sensitivity. It records all events in time sequence and is capable of real time monitoring and data analysis. It performs total quantitative scanning analysis (TQSA), a concept promoted by the center. In a later model the system has the capabilities of auto-monitoring, and channeling contrast microscopy. The resolution is in the range of 1 to 2 μm with up to 8 MeV protons or 2 MeV $_4He^+$. At this university I also had the opportunity to meet Professor Williams, who is engaged in research in the area of process metallurgy, which included the study of the kinetics of metallurgical processes and slag chemistry.

Swinburne Institute of Technology is another teaching organization of note. In addition to preparing students for the degree courses in engineering and computer science, this institute has a Center for Computer Integrated Manufacture. There are almost 2,300 PCs in the institute, and every student is provided one so that each student is computer literate. The objective of the center is to develop a flexible manufacturing system (FMS) that can operate at multiple levels of control and to develop dynamic simulation software that is networked to the cell and is capable of extrapolating system state as well as simulating FMS control algorithms. Another objective of the center is to develop expert systems that would improve the quality of machined components through selection of tooling and cutting parameters and would link to a machining cell and track component accuracy, providing advice on possible causes of out-of-tolerance errors. The institute also has research programs involving robotic assembly of lock mechanisms, robotic polishing of door furniture, thin film coatings of cold/warm/hot forging dies, just-in-time (JIT) forward scheduling in a network manufacturing resource planning (MRP) system, etc.

CONCLUSIONS

1. The Asia-Pacific Workshop on Intelligent Materials Systems and Structures was very successful and productive. It is expected to generate not only new research opportunities in Australia but also close interactions between Australian scientists and U.S. DOD laboratories.

2. The quality of materials science research in the laboratories visited is very good, particularly in the areas of thin film technology and fine ceramics. Australian researchers are eager to work closely with U.S. scientists.

Iqbal Ahmad is the director of the Army Research Office (ARO) Far East. He has a Ph.D. degree in physical chemistry from Imperial College, London, and is a Fellow of the Royal Society of Chemistry, London. Prior to his present position, Dr. Ahmad was a program manager in the area of materials science at ARO, Research Triangle Park, North Carolina.

HIGH PERFORMANCE/HIGH TEMPERATURE MATERIALS IN JAPAN

This paper is based upon a short visit to Japan during which 12 research organizations were visited to discuss high performance materials. This visit was made about 2 years after the author had spent a 1-year sabbatical in Japan. Current research in Japan on intermetallic compounds, functionally gradient materials, composite materials, and high temperature corrosion is used to assess the effort on high performance materials. Changes that have occurred in the research being emphasized over the past 2 years are also discussed. The research effort in Japan is increasing in scope and improving in quality. The commitment to research is long term.

by Frederick S. Pettit

INTRODUCTION

"High performance materials" is an expression being applied to new materials that must be developed to permit devices and machines to perform in ways that are not currently possible. High performance/high temperature materials are restricted to those high performance materials to be used at elevated temperatures. The temperature of use depends on whether metallic alloys, ceramics, or polymers are being considered. Since only metallic alloys and ceramics will be considered in this paper, elevated temperatures are considered to be above about 600 °C. Two of the most important properties of high performance/high temperature materials are mechanical properties and surface stability or oxidation resistance. During a 2-week period (22 July to 3 August 1991), the following laboratories in Japan were visited to discuss research being performed on the mechanical properties and surface stabilities of some high performance/high temperature materials:

- National Research Institute for Metals (NRIM), Tokyo and Tsukuba Laboratories
- National Aerospace Laboratory (NAL), Aeroengine Division, Tokyo
- Ishikawajima-Harima Heavy Industries (IHI), Research Institute, Tokyo
- Mitsubishi Heavy Industries (MHI), Nagoya Aerospace Systems, Materials Research Section
- Kawasaki Heavy Industries (KHI), Jet Engine Division, Materials Research Department, Nishi-Akashi
- Sumitomo Metal Industries, New Materials Research Department, Advanced Technology Research Laboratories, Amagasaki
- Nippon Steel Corporation, Research and Engineering Center, Futtsu City
- Tohoku University, Institute for Materials Research, Sendai
- Kyoto University, Department of Metal Science and Technology
- Osaka University, Department of Materials Science and Engineering
- Tokyo University, Institute of Industrial Science
- Tokyo Institute of Technology, Research Laboratory of Engineering Materials

These are not the only laboratories working on high performance/high temperature materials in Japan, but the research being performed is representative of topics and technical thrusts that are being emphasized throughout Japan. Based upon technical discussions with a number of individuals at these laboratories, it was decided that the following high performance/high temperature materials areas would be of interest to investigators in the United States and other countries:

- Intermetallic Compounds

- Functionally Gradient Materials
- Composite Materials
- High Temperature Corrosion and Coatings Research

In the following sections of this paper these topics will be discussed to identify some of the important research and the investigators in these areas.

INTERMETALLIC COMPOUNDS

An excellent overview of high temperature intermetallics in Japan has recently been prepared by Yamaguchi (Ref 1). There is a very substantial research effort on intermetallics in Japan. Since 1981, the Ministry of International Trade and Industry (MITI) has had a research program on "Basic Technologies for Future Industries." This program is focussed on the following four broad areas: New Materials, Biotechnology, New Electronic Devices, and Superconductivity. There are nine projects in the New Materials area. One of these projects is "High Performance Materials for Severe Environments." The objective of this project is to develop new structural materials for use in severe environments, such as those encountered in various aerospace vehicles, and in different energy generating operations. This effort is to continue for at least 5 more years. Intermetallic compounds are being investigated under the High Performance Materials for Severe Environments project. Research programs are in progress at some national laboratories, universities, and industrial laboratories. Currently, fundamental data are being generated for alloy design, and various fabrication processes are being examined, including melting and casting, rolling and forging as well as powder metallurgical methods.

The Ti-Al System

Intermetallic compounds within the Ti-Al system, namely TiAl, Ti_3Al, and $TiAl_3$, are being studied by a large number of investigators. The overview paper by Yamaguchi (Ref 1) is an excellent source for summaries on relevant research as well as for identifying the important researchers in Japan. In addition to Yamaguchi at Kyoto University, Umakoshi at Osaka University, Hirano at NRIM Tsukuba Laboratory, and Tsujimoto at NRIM Tokyo Laboratory are performing very impressive research on TiAl intermetallic compounds. Some of the projects in Tsujimoto's group at NRIM include:

- Environmental Effects on Mechanical Properties of TiAl Base Alloys
- Effect of Impurities Such as Oxygen on the Microstructure of TiAl Base Alloys
- Effect of Alloying Elements on Mechanical Properties of TiAl Base Alloys
- High Temperature Oxidation of TiAl Base Alloys
- The Relationship Between Microstructure and Ductility of TiAl Binary Alloys
- Coatings for Protecting TiAl

As discussed by Yamaguchi (Ref 1), much of the work on TiAl is focussed on compositions on the titanium rich side of stoichiometry. Cast alloys of such compositions usually contain randomly oriented grains having a lamellar structure composed of TiAl and Ti_3Al. When cast ingots are remelted and unidirectionally solidified by using the floating zone technique, a single lamellar grain can be formed. The TiAl phase is the major component of this structure and there is the following orientation relationship between it and the Ti_3Al:

$$(111)_{TiAl} \parallel (0001)_{Ti_3Al}$$

$$\langle 110\rangle_{TiAl} \parallel \langle 11\bar{2}0\rangle_{Ti_3Al}$$

The TiAl phase contains a large number of twins parallel to the lamellar boundaries. A number of investigators are studying such polysynthetic twinned structures (Ref 2 and 3). The yield stress of this material is dependent on the orientation between the lamellae and the loading axis since two deformation mechanisms are operative. There is easy shear deformation parallel to the lamellae boundaries and hard shear deformation across such boundaries (Ref 2). Umakoshi (Ref 4) has shown that the spacing of the lamellae can be changed by controlling the crystal growth rate and by controlling the aluminum content. A linear relationship exists between the yield stress and the reciprocal of the square root of the lamellar spacing. When the tensile axis is at 90° to the lamellar boundaries, room temperature yield strengths of about 1,400 MPa with approximately 12% elongation are observed. Work is now being directed at improving the ductility more. By utilizing the easy mode of deformation, polysynthetically twinned TiAl crystals have been rolled to 50% reduction at room temperature (Ref 5). This work also includes examining the effects of alloying using elements such as Mn and Cr (Ref 6 and 7).

Aluminum rich TiAl is also being studied, but ductility cannot be improved by attempting to control microstructure (Ref 1), and there has been little improvement in its poor ductility. The compound $TiAl_3$ is being studied by Yamaguchi (Ref 1,3,8), by Umakoshi (Ref 8), and others (Ref 9). This com-

pound has very limited solubility, and polycrystalline specimens usually contain a small amount of a dispersed second phase, often aluminum, which decreases the yield stress and increases the ductility. Single crystals, prepared by the floating zone method, have been used to study the mechanical properties of $TiAl_3$. The stress-strain behavior of $TiAl_3$ and the yield stress depend upon crystal orientation. In Figure 1 some examples of stress-strain curves for single crystals of $TiAl_3$ generated by compression loading at temperatures in the range of 25 to 900 °C are presented (Ref 8). Such results are consistent with the fact that the major mode of deformation in $TiAl_3$ is ordered twinning, which is augmented by slip at high temperatures. Attempts to improve ductility consist of the use of alloying elements to enhance the two major deformation modes (Ref 3) and to attempt to change the tetragonal DO_{22} structure into a more symmetric cubic $L1_2$ structure (Ref 9).

Ni_3Al

As indicated by Yamaguchi (Ref 1), research activity on Ni_3Al is declining. Review papers are available that describe recent progress on the anomalous strengthening and high temperature deformation of Ni_3Al (Ref 10 and 11). Some valuable results have been recently obtained by Hirano of NRIM Tsukuba Laboratory using unidirectionally solidified specimens prepared by the floating zone method (Ref 12-14). Since the floating zone method is used to prepare specimens of a wide variety of intermetallic compounds, a sketch of this apparatus is presented in Figure 2 (Ref 15). The raw material rod is usually prepared by arc melting and drop casting into a copper mold. Use of the floating zone method permits the growth rate to be controlled. Seed crystals are used to grow single crystals and typical growth rates are 2 to 24 mm/h. Hirano has shown that stoichiometric Ni_3Al, with no alloying elements, when grown unidirectionally has high ductilities. Typical results obtained at room temperature are presented in Table 1 (Ref 14). Since specimens exhibited ductility even when the tensile axis was normal to the grain boundaries, he proposes that the grain boundaries are intrinsically resistant to cracking. The floating zone-unidirectionally solidified technique appears to be an attractive method for improving the ductility of Ni_3Al without using alloying additions.

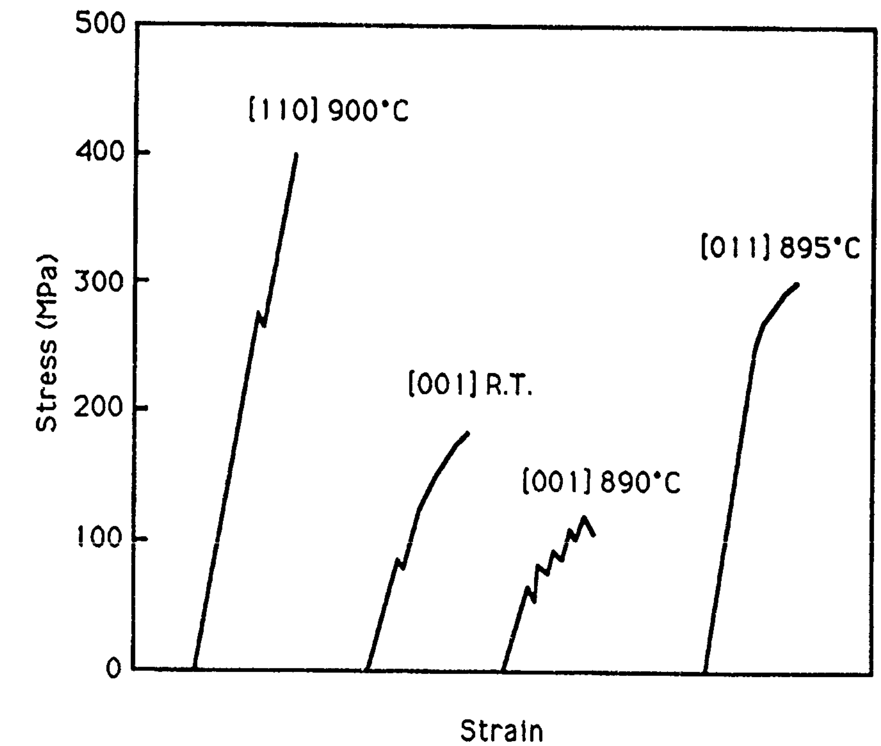

Figure 1. Compression stress-strain curves for single crystals of $TiAl_3$. Reprinted with permission, Figure 6 from an article titled "Deformation Behavior of Single and Polycrystalline Al_3Ti and Al_3Ti with Ternary Alloying Additions," by M. Yamaguchi, Y. Shirai, and Y. Umakoshi, published in *Dispersion Strengthened Aluminum Alloys*, edited by Y.W. Kim and W.M. Griffith, The Metalllurgical Society, 420 Commonwealth Drive, Warrendale, PA, 1988, pp 721-740.

$MoSi_2$

Umakoshi and Hirano are studying the mechanical properties of $MoSi_2$ crystals prepared by the floating zone technique (Ref 16-21). Crystals of $MoSi_2$ are brittle at low temperatures but can be deformed above about 900 °C (Ref 18 and 21). At approximately 900 °C, slip occurred on both (110) and (103) planes, but in the case of slip on (103) planes it was limited to orientations near the <001> direction. Some results are presented in Figure 3, where it is evident that the yield stress is dependent upon temperature and slip system. The yield stress decreases and ductility increases above 1,200 °C. The addition of chromium to $MoSi_2$ was observed not to significantly affect the yield stress for (110) slip; however, a substantial increase was observed for (103) slip (Figure 3). This latter effect was

attributed to solution hardening caused by the Cr addition. Stress-strain curves for $(Mo_{0.97}Cr_{0.03})Si_2$ single crystals show a slight ductility improvement compared to $MoSi_2$.

Other Intermetallic Compounds

The investigators who are studying TiAl, Ni_3Al, and $MoSi_2$ are also studying other intermetallics. For example, WSi_2 (Ref 19), $CrSi_2$ (Ref 21), and $CoSi_2$ (Ref 22) are being studied. The intermetallics Ti_5Si_3 and $TiSi_2$ are also beginning to be studied. The project on High Performance Materials for Severe Environments has identified Nb_3Al as a compound with very attractive high temperature strength. Consequently, work on this compound is being emphasized at universities and industrial and national laboratories. Such emphasis should produce some useful results, but the oxidation resistance of this compound is so very poor that coatings will certainly be necessary for any extended application at elevated temperatures in oxidizing environments.

FUNCTIONALLY GRADIENT MATERIALS

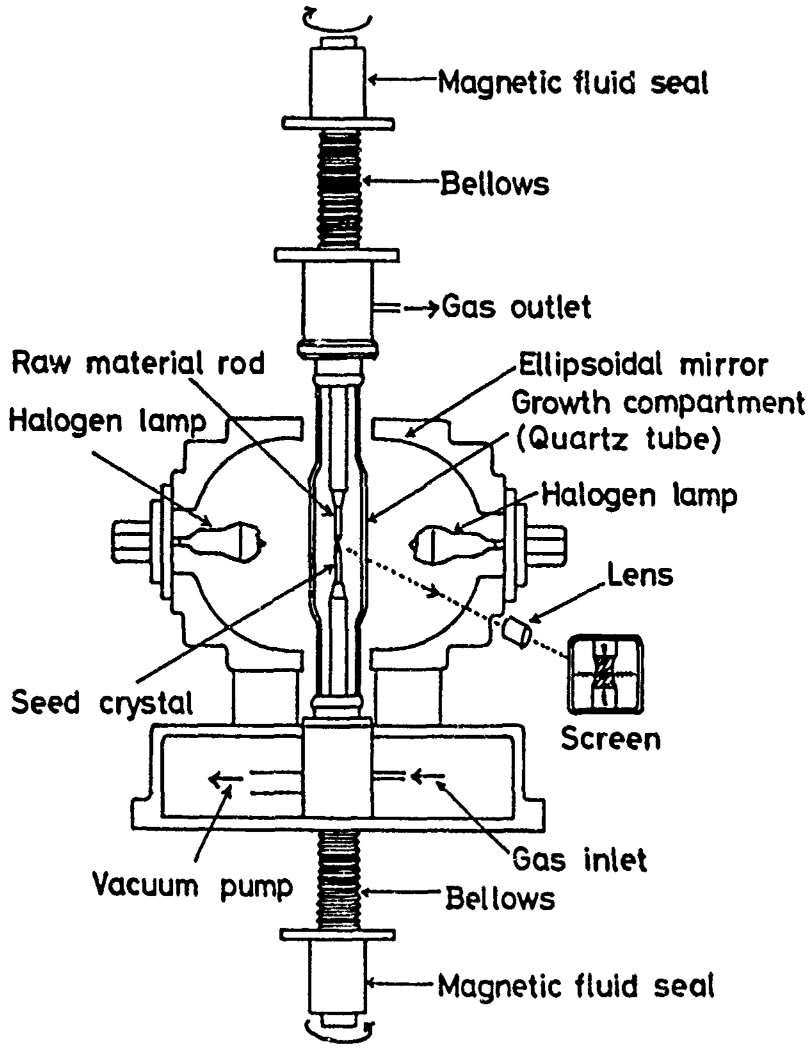

Figure 2. Schematic diagram to illustrate the floating zone apparatus for crystal growth (provided by T. Hirano, NRIM Tsukuba Laboratory).

The concept of functionally gradient materials first surfaced in Japan in 1984, and research to develop functionally gradient materials was initiated in about 1987. A functionally gradient material (FGM) is a synthesized material where composition and, therefore, properties are gradually changed from a material capable of withstanding very high temperature (~2,000 K) to another having properties appropriate for use at 1,000 K. Very often a ceramic material is used at the high temperature region of the FGM and a metallic material is used at the low temperature side; however, in principle, a number of intermediate materials could exist across the FGM. This concept is not new because thermal barrier coatings are currently widely used in gas turbines and the FGM is a type of thermal barrier. The FGM approach to develop new high performance/high temperature materials is being emphasized by numerous investigators, and some interesting results are being obtained.

Hirai and coworkers are preparing FGMs by using vapor deposition processes (Ref 23 and 24). This process, which may be chemical vapor deposition (CVD) or physical vapor deposition (PVD), permits good composition control perpendicular to the deposition surface. Compositionally graded films of Ti/TiC on carbon steel, SiC/TiC on stainless steel, and Ti/TiN on titanium and copper have been fabricated. A FGM film graded from SiC to carbon has also been fabricated on graphite by using $SiCl_4$-CH_4-H_2 at temperatures of 1,673 to 1,773 K. This FGM film did not crack under cyclic high temperature heat flow conditions whereas SiC on graphite with no FGM did crack. In Figure 4 a schematic diagram is presented to show how this SiC/C FGM is proposed to be used to protect a carbon-carbon composite.

Table 1. Results of Specimens Prepared by the Floating Zone-Unidirectionally Solidified Technique

Orientation of Tensile Axis to Growth Direction	0.2% Proof Stress (MPa)	Ultimate Tensile Strength (MPa)	Elongation (%)
Parallel	84	440	102
Perpendicular	162	446	25

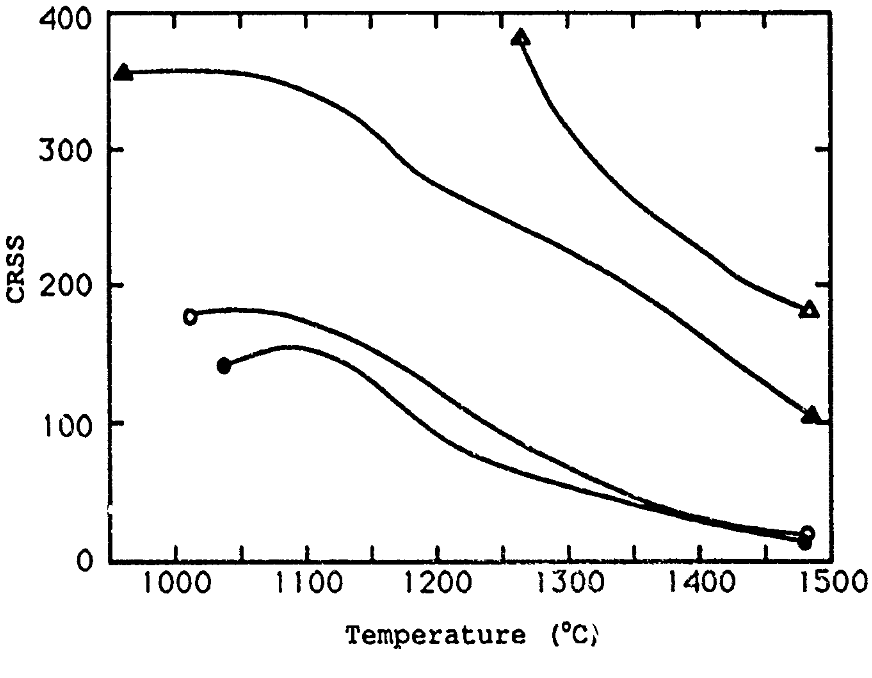

Figure 3. Temperature dependence of the critical resolved shear stress (MPa) for $MoSi_2$ and $(Mo_{0.97}Cr_{0.03})Si_2$ single crystals. Open symbols are for $(Mo_{0.97}Cr_{0.03})Si_2$ and closed symbols are for $MoSi_2$. The triangles give values for the tensile axis oriented along the [001] direction. The circles are values for the tensile axis close to the [132] direction (redrawn, with permission, using data from Ref 21).

Functionally gradient materials are also being developed at the National Aerospace Research Laboratory (Ref 25). The materials being examined are Y_2O_3-stabilized ZrO_2 and NiCoCrAlY on Hastelloy C and on stainless steel substrates. The FGMs are about 600 μm thick and are graded from 100% stabilized ZrO_2 to 100% NiCoCrAlY on the two different substrates. The specimens have been subjected to a temperature differential of 500 °C along with one-dimensional tensile loads. It has been determined that these FGM coatings have good bonding properties compared with conventional thermal barrier coatings made of the same materials.

At KHI Matsuzaki is developing FGMs on TiAl. The surface of the FGM for high temperature is SiC. The composition is graded from 100% SiC through mixtures of SiC and TiC to 100% TiC on TiAl.

The research and development work on functionally gradient materials in Japan is worth continued observation. The effort being expended is substantial and some unique accomplishments are probable.

COMPOSITE MATERIALS

A number of organizations that were visited were involved with work on some type of composite materials. Hagiwara at NRIM (Tsukuba) is attempting to develop titanium alloys for use at temperatures as high as 1,000 °C by using powder metallurgy processes to prepare metal matrix composites. Powders of titanium alloys supersaturated with Y, B, and C are prepared by using a plasma rotating electrode process. These powders are then consolidated via hot isostatic pressing (HIPing) to form a titanium alloy containing a submicron dispersion of oxides and carbides. This approach has also been used where the supersaturated titanium alloy powder is mixed with relatively large size (1-40 μm) powders of either Ti_3Al or TiAl prior to the HIPing step. Such alloys therefore contain two types of dispersed phases, namely, the submicron oxides and carbides and a large size dispersion of Ti_3Al or TiAl. Some improvement in strengths at temperatures between 700 and 800 °C have been obtained in the case of alloys with dispersions of TiAl.

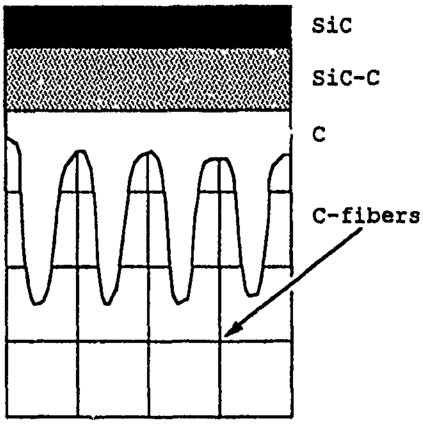

Figure 4. Schematic diagram to illustrate a SiC/C FGM on a carbon-carbon composite (redrawn, with permission, from Ref 23).

Hirai and coworkers (Ref 26) are doing some very interesting work in which CVD is used to fabricate composites. The properties of composites are controlled by the geometric arrangement between the matrix and the dispersion. Moreover, there is good reason to attempt to obtain dispersoids of smaller and smaller size, as well as with controlled shapes. When the size of the dispersoid approaches nanometers, it is very difficult to fabricate composites by mixing powders followed by some type of consolidating process. Because of such problems, it is essential to prepare composites by using an approach whereby phase separation occurs in situ. In situ composite preparation with nanometer dispersoids can be achieved by using a gas (CVD, PVD), a liquid (sol/gel, co-precipitation), a molten alloy (solidification, eutectic reaction), or a solid (phase separation, grain boundary reactions). The CVD method is an excellent method to form nanometer scale deposits as films on different substrates. Hirai and coworkers have prepared a number of nano-scale composites by using CVD. Some typical composites are illustrated in Figure 5.

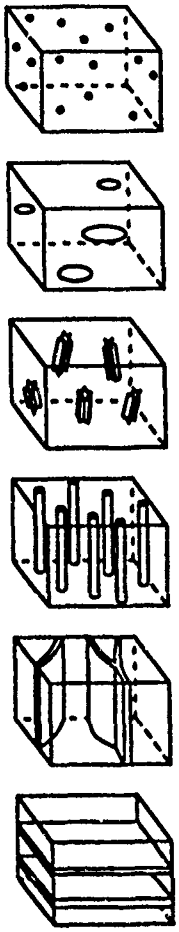

Figure 5. Nanostructures of CVD nanocomposites as presented by Hirai and Sasaki. Reprinted with permission from "In Situ Processing of Inorganic Composites by Chemical Vapor Deposition," by T. Hirai and M. Sasaki, in *Advanced Structural Inorganic Composites*, edited by P. Vincinzini, Elsevier Science Publishers, 1991, p. 541.

In the case of a C-SiC composite having disks of SiC several nanometers in diameter, the carbon and SiC possessed an orientation relationship between each other, and it was reported that this composite had better oxidation resistance than carbon. When particles of C were dispersed in Si_3N_4, these particles formed a three-dimensional network and the addition of 0.2 wt. % of carbon increased the electrical conductivity of the composite very substantially. Other examples have been presented (Ref 26) to show that nanocomposites can be prepared whereby transparency is maintained at elevated temperatures, thermal conductivity is modified, and toughness is improved. Table 2 presents some nanocomposites prepared by CVD and the property altered by using this approach (Ref 27). This technique can also be used to form superconducting oxide films and functionally gradient materials (Ref 26). In Hirai's laboratory, Goto is studying nanocomposites of nonoxide ceramics prepared by CVD. Yamane is working on superconducting oxide films prepared by CVD. Sasaki is preparing functionally gradient materials by using CVD and chemical vapor infiltration (CVI).

There is a very significant effort on composites in Japan. Very great expertise exists in fiber reinforced plastics (FRP). MHI, IHI, and KHI all have very capable workers to produce a variety of components made from these materials including helicopter blades, air brakes, and other airframe parts. In the case of metal matrix and ceramic matrix composites (MMCs and CMCs), the capabilities are not as great as in FRPs but they are still important and at times impressive. At Tokyo University Kagawa is performing studies on the mechanical properties of composites. He is involved with micromechanical modeling and crack growth in carbon/carbon, Ti/SiC, and Si/Al_2O_3 composites. At the National Aerospace Laboratory experiments are being performed on the resistance of carbon/carbon plates to ballistic impact. The point to be emphasized is that research and development is being done on MMCs and CMCs in a significant number of laboratories and valuable advancements can be expected.

Table 2. Some Examples of Nanocomposites Prepared by CVD (Ref 27)

Matrix	Dispersoid	Dispersoid Shape	Dispersoid Size (nm)	Property Altered
C	SiC	disk	3-30	oxidation resistance
Si_3N_4	BN	lamellar	~300	transparency
Si_3N_4	C	spherical	~300	electrical conductivity
SiC	TiC	spherical, fiber	30-300	toughness
SiC	C	spherical, thin layers	30-300	thermal conductivity
Fe, Ni	FeB_x, NiP_x	spherical	30-300	strength

HIGH TEMPERATURE CORROSION AND COATINGS RESEARCH

The topics of high temperature corrosion and coatings research will be described first, based upon discussions at the organizations that were visited, and then based upon some of the papers presented at a symposium recently held at the Tokyo Institute of Technology.

Oxidation studies on Ti-Al alloys are being performed at a number of organizations (Ref 28-31). Shida and Anada at Sumitomo Metal Industries have examined the oxidation behavior of Ti-34.5 wt. % Al containing the elements Mn, Mo, Cr, Si, and Y. These elements were added to the base alloy separately and in amounts up to about 3 wt. %. In all cases multilayered scales composed of $TiO_2/Al_2O_3/TiO_2 + Al_2O_3$ were formed on all of the alloys during oxidation at 900 °C in air. The rates of oxidation were smallest for the alloys with Mo and with Si. The rate of oxidation was increased when Mn was present in the alloy. The effects produced by these elements in Ti-34.5 Al are proposed to be caused by changes in the compactness of the inner $TiO_2 + Al_2O_3$ mixed oxide layer and by oxygen solubility changes in the alloy adjacent to the oxide scale. As mentioned previously (Ref 32), work is also being performed to develop oxidation resistance in TiAl via preoxidation treatments. Recent results (Ref 31) show that protective scales of Al_2O_3 can be formed via oxidation in gases with low pressures of oxygen. These preformed layers do not provide adequate protection, however, at temperatures higher than 900 °C, but this approach may be important for use at temperatures below 900 °C.

Takei and coworkers (Ref 33) at NRIM (Tokyo) are using pack cementation to develop aluminide coatings on titanium alloys as well as TiAl. They determined that a pack mix of 20 wt. % Al, 5% AlF_3, and 75% Al_2O_3 produced the best results. The coatings were deposited by heating in such packs for 5 hours at 1,000 °C. The coating layers on TiAl and titanium alloys were composed of predominantly $TiAl_3$. Such coatings provided protection for Ti-6Al-4V at 900 °C for 12 hours and for less time at 1,000 °C. These coatings provided protection to TiAl at these temperatures for longer times but protection was lost when all the $TiAl_3$ had been removed from the coating by oxidation and interdiffusion.

Iguchi and coworkers at Tohoku University have been studying the oxidation of SiC and Si_3N_4 prepared by the CVD method. Much of the work on SiC has been performed by Narushima (Ref 34-37). This work is concerned with the active to passive transition during oxidation of SiC and the effects of oxygen pressure and temperature. Passive oxidation occurs when a continuous layer of silica is formed on SiC. Active oxidation, on the other hand, involves the formation of gaseous

products where rates are determined by diffusion in a gaseous boundary layer or chemical reactions at the surface of the SiC. The oxygen pressures for the transition from active to passive oxidation have been determined to increase with increasing temperature and with decreasing gas flow rates. Rates for active oxidation have been determined and described in terms of appropriate rate controlling steps.

Ohmura and coworkers (Ref 38) at Nippon Steel Research and Engineering Center are investigating the oxidation resistance of Fe-20 wt. % Cr-5 wt. % Al alloys containing small amounts of La, Ce, Pr, and Nd. The sum total of these elements was varied between 0 and about 0.15 wt. %. Optimum lives during cyclic oxidation at 1,200 °C in air occurred for alloys with concentrations of these elements between 0.05 and 0.10%. These studies showed that the improved oxidation resistance occurred due to increased adherence of the Al_2O_3 scales that formed on these alloys. Furthermore, it was proposed that the better adherence of such oxide scales was due to these elements affecting the growth mechanism of the Al_2O_3 scale such that less compressive stresses developed during growth. The upper limit for beneficial effects of these elements was explained by proposing that incorporation of oxides of these elements into the Al_2O_3 scale caused increased oxidation rates due to rapid transport of oxygen through such oxides. Work is continuing to attempt to develop still better alloys of this type for use in automotive exhaust equipment. This research is impressive. In the case of nickel base alloys, many investigators are now proposing that oxygen active elements improve oxide scale adherence by preventing sulfur from segregating to the scale/alloy interface. The results obtained by Ohmura et al indicate that other factors are important for at least the Fe-Cr-Al system.

At IHI there is much interest in gas turbine materials, but most of the materials used in the gas turbines parts produced by IHI are under license to companies such as General Electric or Pratt and Whitney. Consequently, while significant expertise is present in fabricating state-of-the-art materials for gas turbines, substantial efforts are not evident to improve these materials. IHI has, however, a great variety of engineering interests, one of which is coal gasification. Kihara and coworkers are concerned with fireside corrosion. Laboratory simulation testing is being performed on highly alloyed stainless steels (Ref 39 and 40). Corrosion resistance is improved when the chromium concentration is greater than 20 wt. %. Iso-corrosion curves have been prepared to give corrosion rates as a function of SO_2 pressure in the gas and alkali sulfates in the coal ash.

During the period between 3 December and 7 December 1990, an international symposium on Solid State Chemistry of Advanced Materials was held in Tokyo, Japan. This symposium consisted of two workshops, one on Nonstoichiometric Compounds and the other on High Temperature Corrosion of Advanced Materials and Protective Coatings. The symposium was held at the Tokyo Institute of Technology and was organized by Professor Yasutoshi Saito and Dr. Bulent Onay, both from the institute. The high temperature corrosion workshop was in honor of Professor K. Nishida from Hokkaido University on behalf of his 70th birthday. It consisted of 45 papers of which 27 were by Japanese authors. The time allotted for oral presentations was 15 minutes for invited papers and 10 minutes for the others. Upon conclusion of the day's presentations, the papers were available for more extensive discussions at a poster session period of 2 hours. This procedure proved to be very effective. A large number of papers were presented and extended discussions took place each day at the poster sessions. Some of the papers presented by Japanese authors will be used to provide additional illustrations of high temperature corrosion research in Japan.

The high temperature corrosion workshop whose proceedings are in press (Ref 40) emphasized the following topical areas.

- Fundamental Studies on High Temperature Corrosion of Advanced Materials
- High Temperature Corrosion of Engineering Alloys
- Hot Corrosion of Engineering Alloys and Corrosion of Nuclear Energy-Related Materials
- High Temperature Corrosion of Protective Coatings and Intermetallics
- High Temperature Corrosion of Ceramic Materials

Some of the significant papers presented in these areas are described in the following paragraphs.

Sasayama and Kamiya (Nippon Yakin Kogyo) have studied the morphologies of alumina scales formed on aluminum containing ferritic stainless steels at temperatures between 1,123 and 1,473 K. It was found by using x-ray diffraction (XRD) and transmission electron microscopy (TEM) analyses that various forms of alumina could be formed with different surface morphologies. The slowest growing oxide was α-alumina and this oxide was formed as a smooth scale during oxidation above 1,000 °C. During oxidation between 900 and 1,000 °C, however, the scales contained theta and delta alumina, and these aluminas resulted in higher oxidation rates. These results show that

the transient oxidation characteristics of alumina-forming alloys will depend upon the type of Al_2O_3 that is formed during the initial stages of oxidation.

Narita and coworkers (Hokkaido University) have studied the corrosion of iron-chromium alloys in H_2S-H_2 gas mixtures to identify alloys that could be used in oil-fired boiler tubes. These studies in some cases used preoxidized specimens. A mechanism involving reduction of oxide followed by sulfide formation has been formulated which is proposed to play an important role in the breakdown of Cr_2O_3 scales even when physical defects such as cracks or voids are not present in these scales.

Konno and Furichi (Hokkaido University) examined the use of $LaCrO_3$ as coatings to protect types 304 and 430 stainless steels from oxidation. These coatings were formed from chromate solutions, followed by a heat treatment and consolidation via CO_2 laser irradiation. These coatings evidently provided oxidation resistance since small weight gains (~0.3-0.5 mg/cm^2) were detected after a 1-hour exposure at 1,100 °C.

Yoshiba (Tokyo Metropolitan University) has investigated the interactions between creep processes and hot corrosion attack of the nickel base superalloy IN751. Interactions between creep and hot corrosion were observed as stress-enhanced intergranular attack that resulted in premature fracture. Important characteristics of creep-hot corrosion interactions were identified in mechanistic terms.

Otsuka and Kudo (Sumitomo Metal Industries) are studying the hot corrosion of commercial tube steels in a waste incinerator environment. Their experiments consist of coating specimens with ash deposits followed by exposure to gas mixtures containing SO_2, O_2, CO_2, H_2O, HCl, and N_2 at temperatures between 350 and 450 °C. Weight changes of exposed specimens are determined and detailed characterizations of the exposed specimens are performed. Results are being interpreted by using phase stability diagrams, and acid-base fluxing concepts, to formulate mechanisms for the degradation processes.

Wu and coworkers (Tokyo Institute of Technology) used ac impedance and anodic polarization measurements to monitor the corrosion of alloys in Na_2SO_4-Li_2SO_4 deposits at 700 °C. The corrosion resistance of alloys determined by using these methods was in agreement with the resistance determined by using weight loss techniques.

Nakamori (MHI) has investigated the corrosion behavior of vacuum plasma sprayed NiCrAlY, CoNiCrAlY, and CoCrAlSiY coatings in combustion gas atmospheres to simulate conditions in oil-fired gas turbines. These coatings were deposited on both nickel and cobalt base superalloys and testing was performed by using air-cooled specimens at temperatures between 830 and 1,200 °C. The NiCrAlY and CoCrAlY provided adequate resistance for the exposure times used but the CoCrAlSiY performed poorly. This poor behavior was attributed to reaction between SiO_2 and ash deposits that accumulated on specimens in this test.

Maruyama et al. (Tokyo Institute of Technology) studied the oxidation of silicon-aluminide coatings on molybdenum. These coatings were fabricated by a two step pack cementation process in which silicon was deposited initially (pack mix Si + NH_4Cl + Al_2O_3) followed by an aluminizing treatment (pack mix Al + NH_4Cl + Al_2O_3) at 1,050 °C. The coatings were composed of a layer of Mo_3Al_8 containing precipitates of $Mo(Si,Al)_2$ and Mo_5Si_3. Oxidation at about 1,240 °C resulted in the formation of an Al_2O_3 scale that provided protection for about 20 hours.

Taniguchi et al. (Osaka University) have attempted to preoxidize specimens of TiAl in a Rhines pack containing Cr_2O_3 and chromium. The specimens were then oxidized at 1,023 °C in oxygen at 1 atm. Preoxidation significantly improved the oxidation resistance of TiAl. Adherent Al_2O_3 scales provided protection. The presence of chromium was also suggested to improve the protectiveness of the preformed Al_2O_3 scale.

Imai et al. (Japan Atomic Energy Research Institute) formed SiC coatings on graphite by heating specimens in silicon monoxide at 1,300-1,380 °C. These SiC coatings were reported to be resistant to thermal cycling and provided oxidation resistance.

Wada and Yoshiba (Tokyo Metropolitan University) have examined the corrosion of ceramics such as Al_2O_3, stabilized ZrO_2, Si_3N_4, and SiC at 900-1,200 °C in V_2O_5-Na_2SO_4-NaCl mixtures. The corrosion properties of these ceramics were dependent upon impurities with more corrosion resistance being developed in the most pure materials. The addition of V_2O_5 to the Na_2SO_4-NaCl deposits generally caused increased corrosion.

The high temperature corrosion and coatings research in Japan is impressive. A number of problems are being studied. The work is usually related to some specific problem, but often the approaches are concerned with mechanisms for the observed degradation. The researchers are often young, compared to those in the United States. Significant accomplishments in this area are likely, especially within a period of 5 to 10 years from now.

ADDITIONAL DETAILS CONCERNING MATERIALS RESEARCH IN JAPAN

All of the topics that were discussed and observed during this 2-week visit to materials research laboratories will not be discussed in detail. There is a very substantial interest in superalloys in Japan by companies such as MHI, KHI, IHI, national laboratories, as well as universities. As mentioned in a

previous paper (Ref 32), single crystal superalloys and oxide dispersed superalloys are being studied. The advancements in Japan over the past 2 years in superalloy development have not been substantial. Superallr/s equivalent to CMSX 4 and PWA 1484 are available and more advanced systems are being developed, but the emphasis seems less than it had been previously. Horibe at NRIM (Tokyo) is performing research on crack propagation in ceramics such as SiC. Iguchi at Tohoku University is doing some very good research concerned with extractive metallurgy processes. There is a sizeable research effort in Japan on materials to be used in nuclear reactors and radiation damage effects. For example, very elegant TEM studies on defects induced in ceramics by radiation are being performed at the Tokyo Institute of Technology where resolutions of about 3 Å have been achieved.

It is also important to emphasize that research facilities throughout Japan are being upgraded and expanded. As an example, Nippon Steel has just completed its new research and enf neering laboratory. It is in Futtsu City, which is about a 1-hour train ride from Tokyo. It will be Japan's largest private-sector research laboratory. A staff of about 1,200 will be employed: 400 researchers, 400 research assistants, and 400 engineers. Equipment is beginning to be installed and some research is already in progress. It is truly a very impressive facility and unquestionably will be responsible for significant technical breakthroughs in the future. This center will not only be involved with steel research, development, and engineering but also new materials and new technologies. While the Nippon Steel Research and Engineering Center is the most notable example of the emphasis that is placed upon materials research, numerous other examples are evident. At Tokyo University a Research Center for Advanced Science and Technology has been established. This center is directed at developing advanced materials, advanced devices, and advanced systems. At the National Aerospace Laboratory an extremely well equipped materials test laboratory has been completed. A number (Ref 7) of the latest model Instron testing machines with environmental controls, and computer operated, are available.

CONCLUDING REMARKS

During a 1-year stay in Japan 2 years ago, this author concluded that materials research in Japan was important, but that almost all of the research was direct-application oriented. Moreover, most often the research was on topics initially discovered in other countries. During the present visit, signs are evident that such views will not be accurate in 5 to 10 years. More research is being done to determine mechanisms and because it is interesting. The commitment to long term research is evident. There is, and will be, good research in many countries throughout the world that certainly will be as good as or, in some cases, better than that in Japan. However, there should not be any question that important materials research accomplishments will be achieved in Japan. At the present time research on Nb_3Al is being emphasized in Japan, while the effort has been curtailed in the United States because the problems of oxidation are too severe for applications where part failures would cause catastrophic effects. It will be interesting to see how this research in Japan on Nb_3Al progresses.

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UNITED STATES-JAPAN COOPERATIVE PROGRAM IN NATURAL RESOURCES (UJNR)

A new subdivision of the United States-Japan Cooperative Program in Natural Resources, Deep Marine Technology, met for the first time in Hakone, Japan. Technical advances and announcements of innovative programs by the Japanese and future research plans by the Americans highlighted the meeting. Brief reviews of papers in the four topical areas (biology, observation platforms, geology, and programmatic research) are presented.

by Pat Wilde

INTRODUCTION

The United States-Japan Cooperative Program in Natural Resources (UJNR) was established in 1964. The UJNR program of science and technology interchanges now has 16 panels of which Diving Physiology and Technology is one of the most successful and longest running. The major focus of the panel, generally called the Diving Panel, is diving physiology and attendant submersible research. The Japanese coordination is through the Japan Marine Science and Technology Center (JAMSTEC), while the United States effort is through the National Oceanic and Atmospheric Administration (NOAA) of the Department of Commerce. Formal exchanges between scientists are held every 2 years, generally alternating between countries. An innovation was introduced to the Diving Panel meeting this year at Hakone, Japan, with the operation of two simultaneous research sessions. The major session continued to focus on diving physiology as the "Hyperbaric Group," but recognizing that technology was advancing in the submersible field, a second session was added on deep marine technology as the "Deep-Sea Science Group." The focus of this new session was "deep-sea research that can be conducted from a submersible, ROV (remotely operated vehicle), AUV (autonomous underwater vehicle), or towed system in the Pacific Ocean in the next 5-10 years." This article reports on the sessions of the Deep-Sea Science Group.

The new group attracted 22 speakers, 13 from the United States and 9 from Japan. The sessions were co-chaired by Dr. Hiroshi Hotta of JAMSTEC and Dr. Sylvia Earle, chief scientist of NOAA.

BIOLOGICAL REPORTS

The initial talks were on biology. Dr. Chiaki Kato, JAMSTEC, discussed deep-sea microbiological research at JAMSTEC, describing the DEEPSTAR (Deep-sea Environment Exploration Program Submarine Terrain Animalcule Retriever) initiative, which will move into a 6-story, 6,000-m^2 new facility at JAMSTEC in 1993. This paper was co-authored by Dr. Koki Horikoshi. Dr. Kato also described the development of an isolation chamber and collection system as well as a sterilized mud sampler for the SHINKAI 6500 submersible.

Dr. Laurence Madin of Woods Hole talked on the use of submersibles for research on deepwater zooplankton and nekton, limiting his discussion to intermediate midwaters of 1,000 meters or less. U.S. research focuses on taxonomy of organisms, behavior, bioluminescence, benthopelagic organisms, and detritus as marine snow. He noted that a major source of marine snow was from gelatinous mucous of appendicularians where the actual animal was much smaller than its contribution to the organic detritus. There is interest in the biology of deeper waters, but at present access to submersibles and appropriate technology limits the realistic expectation to investigations in midwaters.

Dr. Tetsuo Hamamoto of the DEEPSTAR group at the Riken Institute reported on work with his colleague, Dr. Koki Horikoshi, on characterization of an amylase from a psychrotrophic *Vibrio* isolated from a deep-sea mud sample. He stressed the value of the studies of extremophiles as they are found surviving at both high and low pH (<3, >9), temperatures (<10 °C, >70 °C), high salinity (>150 ppt), in the presence of >1% organic solvents, high concentrations of heavy metals such as Hg and Cd and sulfides, and at great pressure. He sees the potential application of such organisms as insights in the design of biocatalyzers for high temperature and pressure industrial processes.

Dr. W. Waldo Wakefield of the National Marine Fisheries Service of NOAA talked on the general topic of the application of marine technology to research needs in deep-sea biology for the coming decade. He used as an example studies of the carbon requirements of the benthic boundary layer which combine examination of the passive rain of carbon samples by sediment traps to respiration studies both of nekton and infaunas in chambers or by electrodes. He noted that the flux is just not that of simple rain of detrital carbon from above but involves animal migration via eggs and larva to along bottom down slope flows. As expected, the in-situ metabolic studies show that the carbon demand from the sediment community far exceeds that of the free swimming organisms. However, carbon budgets show high temporal and spatial variability with a real time mismatch of supply and demand with the apparent paradox that demand exceeds measured supply. He also described the remote vehicle used in such studies of sedimentary metabolism developed by Dr. Smith and Dr. Rymers of Scripps.

Dr. Takashi Okutani of Tokyo University gave a paper titled "Marine Biological Wealth Brought by Submersibles--New Light to Molluscan Systematics as an Example," co-authored by Dr. Katsunori Fujikura and Dr. Jun Hashimoto, both of JAMSTEC. Dr. Okutani reported on the value of the use of submersibles in the discovery of new communities, especially those of vents where the bathymetry is usually too rough that prior researchers didn't bother to dredge them. Some of the snails found close to hot vents apparently have symbiotic sulfur bacteria. Accordingly, he suggests that "molluscan systematics as well as physico ecology of deep-sea animals" will have to be revised in light of the discoveries made possible by submersibles.

Dr. David Stein of the National Undersea Research Program (NURP) of NOAA presented "Deep Nekton: Prospects for Future Studies Using Undersea Vehicles." He stressed the need for in-situ trap studies, which only can be done by submersibles. Dr. Stein posed the problem of illumination in the deep sea. It is required for humans to see and to manipulate samplers. But light is not the natural environment in the deep sea, so how valid are the census measurements and even the behavioral studies done in visible light? Could it be that the old midwater trawl census data are more valid than those taken by submersibles or by cameras using visible light? He suggested investigation of other sources of illumination to provide a more natural sampling environment. Also, Dr. Stein indicated a need for a study on the avoidance of nekton of submersibles. Due to the lack of data and the large area of the deep ocean, he supported more use of unmanned vehicles, which are much cheaper and safer to operate than manned submersibles.

Dr. Sylvia Earle of NOAA talked on the results of the SHINKAI 6500 dive and deep-sea science and technology needs. Dr. Earle was fortunate to be one of the first Americans to dive in the SHINKAI 6500 (depth of 6,500 meters), the deepest diving research submersible. As noted above by Dr. Stein, the problem of the influence and impact of artificial light on natural populations accustomed to total darkness or at most bioluminescence is a nagging one. Dr. Earle proposed using the Army's night vision infrared goggles, which detect only ambient light The experiment was done with red filtered light with baited fish attractants. Accordingly the submersible was essentially invisible to the biota. She reported on such phenomenon as bioluminescent ink from squid, commenting that 13 phyla demonstrate bioluminescence.

SEAFLOOR OBSERVATIONS AND OBSERVATORIES

Dr. Yoshio Ueda of the Japanese Hydrographic Department, representing his colleagues Drs. Akira Asada, Fusakiti Ono, Yoshio Kubo, and Motoji Kawanabe, reported on the ROV MARCAS 2500's survey work in Sagami Bay to select a site for a seabottom observatory to observe crustal movements. In conjunction with the survey, tests were run on horizontal distance and vertical displacement devices. The goal was to resolve centimeters over a distance of 1 km. Of the various signal sources tried, chirping at between 30 and 50 kHz gave the best results. The vertical meter uses a pressure sensor with a target resolution of 1 cm.

Dr. Makoto Yuasa of the Geological Survey of Japan, in his paper titled "Submarine Pumice Volcano - A Submersible Study," has proposed that Myojin Knoll in the Izu-Ogasawara (Bonin) Arc may be a new type of acidic pumice submarine caldera, which is characterized by a high gravity anomaly but a weak magnetic anomaly. Submersible studies show that the knoll is constructed of layers of stratified pumice and dacitic lava that provide the framework for the volcano.

Dr. John Lupton of the University of California, Santa Barbara reviewed research needs for in-situ sampling and data collection at submarine hot springs and cold seeps. Dr. Lupton also discussed the U.S. RIDGE program and its various international and national counterparts as an example of an integrated research program involving many institutions but focusing on a geologically specific topic. One of the characteristic features of the oceanic ridge-rise system is the vents which, because of their small size, transitory nature, and sometimes hostile environmental conditions, require specialized and demanding sampling devices and

strategies. The steep chemical and thermal gradients associated with many vents make taking uncontaminated and sequential samples a real challenge. He indicated that technological development or improvement is required in ultra-precision navigation, rapid water sample collection, data collection at high sampling rates, repeat sampling by autonomous vehicles, and the development of better data links and new in-situ sensors for seafloor observatories. He particularly stressed the need for event detection, possibly by acoustic tomography, of the episodic large releases (burps) of water and gases from active vent systems.

Dr. Kiyouki Kisimoto of the Geological Survey of Japan, in his paper "In Situ Measurements and Observation of Hydrothermal Activity - A Feasibility Study of New Usage of Submersible," discussed the results of the Franco-Japanese STARMER submersible/SeaBeam survey of the Triple Junction in the North Fiji Basin. The group found a white smoker where gypsum rather than sulfides were being precipitated. The STARMER program was a 5-year venture ending in 1992. A new Ridge Flux (energy and mass) program similar to STARMER but including a seafloor laboratory was proposed. The projected areas of study are the Southeast Pacific Rise and Back-Arc spreading centers in the Western Pacific. The starting date is proposed as April 1992, again to run for 5 years.

Dr. Peter Rona of the NOAA Atlantic Oceanographic and Meteorologic Laboratory (AOML) in Miami indicated in "Frontier of Seafloor Hydrothermal Research" that back-arc basins are an exciting new area of research where the various vent processes occur but with potentially a different set of chemical, thermal, mineralogic, and biologic characteristics due to the different composition of the host rock through which the hydrothermal fluids circulate, i.e., basalts in the oceanic ridges and andesites and rhyolites in the back-arc basins. Dr. Rona considers this a logical step in the completing of the cycle of the impact of the discovery of the vents as a major process in geologic cycling buffering oceanic, sedimentary, and atmospheric compositions as well as a principal mechanism for economic mineralization. He demonstrated the variability of vent processes by examples of a comparative study of hydrothermal systems from the TAG vents in the Atlantic with the Juan de Fuca system. Investigation of the buoyant plume rising from the vents with the submersible TURTLE was augmented by sonar imaging to track the whole plume. At neutral buoyancy the Atlantic plumes were relatively cold and "fresh" as compared to the Pacific plumes, which were hot and salty. An interesting biologic contrast between oceans was that no tube worms or clams were found in the Atlantic vents where shrimp (inedible due to the sulfides) swarmed near the vents.

"Establishing a Seafloor Observatory: NOAA VENTS Program's Long-Term Seafloor and Hydrothermal Monitoring Experiment" was the topic of Dr. Stephen Hammond's (NOAA's Marine Science Center in Oregon) talk. He outlined some of the chemical fluxes at the vent sites on the Juan de Fuca Ridge where silica is added and phosphorus is subtracted from the oceans. Besides the usual physical and chemical monitoring suggested for on-bottom observatories, Dr. Hammond pointed out the importance of studying mega-plumes, particularly with respect to the total heat budget of the ocean. The proposed NURP package would be deployed for a year then recovered. Existing monitoring instrumentation includes harmonic-tremor sensors, tilt meters, bottom pressure sensors, temperature sensors and moored arrays of current meters, transmissometers, and sediment traps. Tests are ongoing on an in-situ chemical sensor deployable from submersibles, ROVs, or bottom sitting. In the fall of 1991, an episodic event detecting device monitoring T-phase signals from submarine eruptions will be deployed followed by an acoustic array for measuring horizontal crustal extension. The pilot seafloor observatory is planned to be in place in 1994-1995 on the Juan de Fuca Ridge as a cooperative venture between the VENTS program and the RIDGE project.

LCDR George Billy of the U.S. Navy outlined the U.S. Navy deep submergence program deep ocean science support. LCDR Billy described the upgrading of the two Navy research submersibles, the SEACLIFF to 20,000 feet and the TURTLE to 10,000 feet. This submersible capability is augmented by ROVs including two SUPER SCORPIO work vehicles. These systems are supported by a civilian manned support ship, M/V LANEY CHOUEST, a 240-foot vessel with berthing for 40 scientists/technicians in addition to the crew. Besides the over-the-side handling capabilities, the LANEY CHOUEST has a SeaBeam surveying system, an integrated deep submergence vehicle (DSV)/ROV navigational system, dynamic position, and well equipped and spacious wet and dry laboratories. Access to these facilities has been improved by a cooperative agreement between the National Undersea Research Program of NOAA and the U.S. Navy.

GEOLOGICAL STUDIES

Active hydrothermal vents in the Okinawa Trough in the back-arc basin behind the Ryukyu Arc was the topic of Dr. Kantaro Fujioka's talk, "Tectonic Similarity Between Okinawa Trough and Northeast Japan Arc at 15 Ma." He was speaking in behalf of his colleagues at the Deepsea Research Group at JAMSTEC. In this case, the vents are in a belt of subduction rather than

on the ridge-rise crest, although the vents occur along a back-arc rift of continental character rather than oceanic. Black smoker with giant clam communities were observed during dives in the SHINKAI 2000. The tectonic picture of the economic Kuroko land-based hydrothermal deposits 15 million years ago is similar to that found today in the present Ryukyu Arc. Active vents also have been discovered behind the Izu-Bonin Arc, but in a more oceanic setting. Comparative studies between the two rift systems in tectonically different back-arc areas are proposed. Continuing on this theme, Dr. Hiroshi Hotta, also of the Deepsea Research Group of JAMSTEC, discussed a proposal for the across submersible transect around the Japanese subduction zones. This will include dives by both the SHINKAI 2000 and SHINKAI 6500 comparing (1) the Continental Rift versus the Oceanic Rift, (2) accretion versus nonaccretion, with (3) an across-arc submersible transect. Dr. Hotta also described a proposal to place a geological-geophysical observatory in the Japan Trench as part of the MODEPAC program of monitoring of the motions of the Pacific Plate. The initial phase is to start in April 1992 pending funding approval.

Dr. Kazuo Kobayashi, representing his colleagues Masaharu Watanabe and Suguru Ohta of the Ocean Research Institute of the University of Tokyo, gave a presentation via video tape of the deep-sea monitoring system onboard the R/V HAKUHO MARU. The system is connected to the ship by an optical fiber/electrical composite cable with 6 kilometers of wire on the drum. The on-bottom package includes stereo color television, a pair of still cameras, four 300-watt halogen lamps, CTD (conductivity-temperature-depth), a six-bottle rosette water sampler, and a signal-operated clamp for remote release of special instruments such as pop-up OBS (on-bottom seismometer), etc. An acoustic transponder is attached to the frame for location. There is no individual maneuvering capability so the system is hung in the water or towed at speeds under 1 knot along the bottom. Ancillary information as to position, time, etc. is superimposed on the video tape record and the output of the recorder is displayed on two video screens on deck. The video tape presentation showed operations of the ship and the system during research cruises to the Japan Trench and the Manus Basin.

PROGRAMMATIC DEEP-SEA RESEARCH

Dr. Donald Heinrichs of the National Science Foundation (NSF) discussed the current policy and directions of that funding agency. In the near term, emphasis will be on the Global Change Initiative with the RIDGE program an active component. NSF's evaluation criteria with respect to marine research programs include (1) adequate scientific and technological planning, (2) integrated approach, and (3) international cooperation.

Prof. Alexander Malahoff of the University of Hawaii outlined the cooperation between NOAA's National Undersea Research Center within the umbrella of Hawaii's Undersea Research Laboratory. The emphasis is on submarine volcanism in the tropical regions. A keystone of the program will be the establishment of an on-bottom volcanological observatory on Loihi Seamount, the "next" Hawaiian island just south of the big island of Hawaii. In 1992 monitoring will begin routinely with the laying of a fiber optic cable from Loihi to the southern tip of Hawaii. In support of the Loihi observatory and other operations, the 220-foot KAIMIKAI-O-KANALOA is under construction with a completion date of the summer of 1992. Besides supporting various on-bottom and over-the-side instrument packages, this ship will operate the PISCES V submersible and a modified remote-controlled vehicle (RCV)/ROV.

The closing speaker was Gregory Stone of NOAA, currently on a 2-year tour at JAMSTEC, discussing "Deep Ocean Science Needs, NOAA, UJNR, JAMSTEC." Drawing from his paper (with William S. Busch) titled "Deep Ocean Science and Facility Needs" from the summer 1991 issue of the *Marine Technology Society Journal*, Stone gave the results of a survey of 62 submersible-using scientists on research needs in the range of 4,000 to 11,000 meters. The peaks of interest were in the depths of 5,000 to 6,000 meters, corresponding to the flanks of the Ridge-Rise system and the abyssal plains, and 10,000 to 11,000 meters, representing the oceanic trenches. Some 80% of the respondents would be satisfied with 8 hours or less of bottom time. Stone noted that the nations now in the forefront of submersible development are Japan followed by France. One feature of the Japanese approach to deep-sea research was the extensive use of towed and ROVs in pre-site surveys prior to actual dives with expensive submersibles. This not only enhanced the science that could be planned during the short dive times but provided more regional background data and technological experience, which is not accomplished with the general U.S. policy of dive with limited pre-site surveys.

SUMMARY

Japanese progress in deep ocean technology is developing rapidly on several fronts. They have new and technologically advanced submersibles and are planning ones with even greater depth capabilities. They are using submersibles and sophisticated remote

vehicles to do the preliminary survey work for pioneering deep-sea observatories and remote instrument stations, planning to link them together and to the beach. This would give them a quasi-synoptic capability for seafloor monitoring. Much of their efforts are justified not as pure science but as filling practical and publicly understood needs such as for earthquake monitoring, fisheries evaluation, environmental testing, and the development of new medicines. In this way the Japanese efforts are seemingly well financed and actively supported by both the government and industry. American efforts are characterized by innovation, but compared to the Japanese we are paying the price for the diverse sources of funding and the fragmentation of oceanographic efforts. Unlike the Japanese programs with a readily identifiable "practical side," even the U.S. programs with a multidisciplinary focus like RIDGE are sold on the pure science side, essentially unintelligible to the general public or even to scientists outside the particular areas. Accordingly, in this time of fiscal restraints on research, much of what was proposed by American scientists appears to be just that: proposals. As such, they are unlikely to be either funded adequately, realized imperfectly, or carried out by workers in other countries. On the other hand, a comprehensive general oceanographic effort by a single state such as that in Hawaii, although on a smaller scale, has many similarities to the Japanese programs. Hawaii is an island state like Japan; thus, there is a high awareness of the importance of the oceans in the political, private, and public sectors. Also, being a small state there is only one academic/research institution located in the capital to engage in marine research.

In general, the increasing ability to operate efficiently and effectively at deeper depths either remotely or in human occupied submersibles indicates that both the technology and the research side of investigations in the deep ocean will continue to develop and produce valuable results. It is not unlikely that within 10 years there will be no depth in the ocean inaccessible to human inquiry.

Pat Wilde joined the staff of the Office of Naval Research Asian Office (ONRASIA) in July 1991 as a liaison scientist specializing in ocean sciences. He received his Ph.D. in geology from Harvard University in 1965. Since 1964, he has been affiliated with the University of California, Berkeley in a variety of positions and departments, including Chairman of Ocean Engineering from 1968 to 1975 and Head of the Marine Sciences Group at the Lawrence Berkeley Laboratory (1977-1982) and on the Berkeley campus (1982-1989). He joined ONRASIA after being the Humboldt Prize Winner in Residence at the Technical University of Berlin. Dr. Wilde's speciality is in paleo-oceanography and marine geochemistry, particularly in the Paleozoic and Anoxic environments. He maintains an interest in modern oceanography through his work on deep-sea fans, coastal and deep-sea sediment transport, and publication of oceanographic data sheets showing the bathymetry with attendant features off the West Coast of the United States, Hawaii, and Puerto Rico.

SOUTH PACIFIC ENVIRONMENTAL PROGRAM (SPREP) BIODIVERSITY WORKSHOP AND MARINE MAMMAL CONSERVATION PLAN

The South Pacific Regional Environmental Program (SPREP) organized the 22 South Pacific Island countries and administrations that participate in SPREP to meet in Port Vila, Vanuatu, for a biodiversity workshop. The group identified environmental problems specific to island countries and drafted a document to be forwarded to the Global Biodiversity Convention recommending specific action in the South Pacific. A Marine Mammal Conservation action plan was developed for the western Tropical Pacific; it includes developing education/public awareness programs for marine mammals, obtaining information about species abundance and distribution, and identifying marine mammal conservation issues. This marine mammal conservation plan is modeled after the International Union for the Conservation of Nature (IUCN) global marine mammal action plan.

by Gregory Stone, Michael Donoghue, and Stephen Leatherwood

INTRODUCTION/ BACKGROUND

The South Pacific Regional Environmental Program (SPREP) held three consecutive meetings in Port Vila, Vanuatu, from 21-30 October 1991. The first was a workshop on the South Pacific's preparations for the June 1992 United Nations Conference on Environment and Development (UNCED), the second was a workshop on Biodiversity and Conservation, and the third was a meeting on Ecosystem Classification. This is a report of the Biodiversity and Conservation Workshop, with special emphasis on the marine mammal conservation plan that was developed during that meeting.

All meetings were held in the conference facilities of the University of the South Pacific, Port Vila, Vanuatu. Representatives from the following countries/administrations attended the meetings (approximately 50 people total): American Samoa, Australia, Cook Islands, Fiji, French Polynesia, Kiribati, Palau, Tonga, Tuvalu, United States, Vanuatu, and Western Samoa.

For the UNCED meeting, SPREP supported representatives from each country and administration, one person for environmental affairs and one for development; for the other two workshops SPREP supported one environmental person from each country/administration.

In addition, there were observers and specialists from the following organizations: Foundation of the Peoples of the South Pacific International, Greenpeace, International Union for the Conservation of Nature (IUCN) Cetacean Specialist Group (Texas A&M University), Royal Forest and Bird Protection Society of New Zealand, The Nature Conservancy, United Nations Development Program, U.S. National Oceanic and Atmospheric Administration (NOAA), University of the South Pacific, and New Zealand Department of Conservation.

SOUTH PACIFIC REGIONAL ENVIRONMENTAL PROGRAM

SPREP grew out of the United Nations Environment Program (UNEP) and the South Pacific Commission. Located in Noumea, New Caledonia, at the South Pacific Commission headquarters, SPREP works on behalf of 22 island governments and administrations of the South Pacific Region. Funding comes mainly from the United Nations and other South Pacific Commission countries, namely Australia, New Zealand, France, the United States, and the United Kingdom. SPREP is recognized as the principal environment program for the countries of the South Pacific, in partnership with the South Pacific Commission, the United Nations Environment Program, the Forum Secretariat, and the Economic and Social Commission for Asia and the Pacific.

SPREP was inaugurated in 1982 with an Action Plan that included the following mandates:

(1) Identify experts and institutions with specific skills required to assist Pacific Island governments in solving their environmental problems.

(2) Ensure that monitoring of the state of the environments is continually underway to enable the early detection of potential problems.

(3) Facilitate exchange of environmental information among experts, institutions, governments, and the community.

(4) Develop and increase expertise, especially through training programs in environmental management skills.

BIODIVERSITY WORKSHOP

The environment officers from the various island countries and administrations listed above were present at the Vanuatu Biodiversity Workshop primarily to identify and discuss conservation and biodiversity issues in the SPREP member nations and to discuss the position of the South Pacific Island countries vis-a-vis the Global Biodiversity Convention. The chairman was Mr. Demei Otobed, Chief Conservationist, Bureau of Resources and Development, Ministry of Natural Resources, Republic of Palau.

The workshop was structured around the presentation of working papers that were followed by open discussion among workshop participants. Titles of working papers included:

- Conservation of Biological Diversity - An Overview
- Pacific Island Biodiversity: A Basis for Ecological and Economic Survival
- Project Formulation Framework
- SPREP Regional Marine Mammal Conservation Program
- SPREP Regional Avifauna Conservation Program
- Global Biodiversity Convention - An Overview

Within this framework, the workshop raised awareness among the SPREP member countries about global and regional biological diversity issues, such as species extinction rates, the unique needs of islands, and the special conservation considerations for underdeveloped countries. It was widely agreed by all present that the local economies and native social systems must be maintained when implementing conservation regimes. It was noted that up to 90% of rural economies in the South Pacific are actually based on long-established practices that promote biodiversity, i.e., based on a healthy and robust natural environment that produces food, raw materials for domestic use, and export products. Dr. Randy Thaman, of the University of the South Pacific, stressed that biodiversity was future capital of the region and must be maintained. He added that the value of island biodiversity has probably been grossly underestimated because there has yet to be a comprehensive survey where researchers travel out into local communities, talk to people in native languages, and learn the medicinal and other uses of plant and animal products. There are, he suggested, many such undescribed values within the ecosystems of the South Pacific. Many other participants also stressed the need for researchers and programs concerned with the environment of the South Pacific to use and integrate local knowledge from native people. Integrating scientific methods and surveys with local knowledge is the most expedient way to gather data on the species distribution and abundance of the region. The most important first step in identifying conservation problems is filling the gaps in data on ecosystems and species of the region.

The meeting also reviewed the Global Biodiversity Convention line by line to propose changes for the next round of official negotiations, currently being undertaken under the auspices of UNEP. This convention is designed to bring together various efforts and concerns for global biodiversity that could rationalize current activities and give direction to future efforts to conserve biological diversity. This is a world-wide convention with several more rounds of negotiations planned prior to the UNCED Brazil conference in June 1992. It is intended that this treaty be completed by the time of the UNCED conference. However, this meeting was only concerned with the needs and

positions of South Pacific Island countries.

Participants agreed that Pacific Island countries should participate in the negotiating sessions and present a coordinated approach to the convention. Requests will be made to UN agencies and other organizations to assist Pacific Island governments financially in attending negotiations. It was also agreed that SPREP will coordinate the Pacific Island delegation response and provide advisory services. This workshop also emphasized the need for the convention to: (1) recognize the fragility, poor understanding, and limited knowledge of tropical ecosystems; and (2) emphasize that biological diversity in the South Pacific region is especially threatened by the predicted effects of climate change, particularly sea level rise. These effects include the disruption to or loss of entire island ecosystems.

MARINE MAMMAL CONSERVATION PLAN FOR SPREP

Marine mammals (whales, dolphins, porpoises, dugongs, and seals) are vital and highly visible components of aquatic and marine environments in the South Pacific. Of the approximately 80 species of whales and dolphins in the world today, 32 are confirmed or can be reasonably expected to occur in the SPREP region. There are populations of dolphins or small whales in rivers, estuaries, bays, and virtually all marine environments throughout the region. As many as nine species of great whales may occur in some part(s) of the vast SPREP area, as residents, seasonal migrants, or occasional wanderers. At least three species of seals wander into the area occasionally from their principal habitats further south or north. Dugongs can be found, albeit in diminishing numbers, in seagrass beds around Papua New Guinea, the Solomon Islands, Vanuatu, Palau, and New Caledonia.

One of the responsibilities of SPREP is to assess and conserve the marine mammals of the region. Towards this end, a steering committee was formed and a draft marine mammal action plan was developed during the Port Vila Biodiversity Workshop. The initial steering committee for this plan consists of the authors of this report and Paul Holthus, Scientific Officer, South Pacific Regional Environment Programme, P.O. Box D5, Noumea, New Caledonia. The overall aim of the SPREP Marine Mammal Conservation Programme (MMCP) is to implement a well conceived strategy to conserve the diversity of marine mammal species as part of healthy marine, estuarine, and riverine ecosystems in the SPREP region. It was decided that the required actions will include:

- **Marine mammal data needs and education.** As with other conservation issues identified during the meeting, the biggest problem with the marine mammals was the lack of information on species present in the area, distribution, and abundance. There have been few published papers on marine mammals of the area, so most information comes from unpublished reports, whaling records from the 18th and 19th centuries, and inferences of distribution and abundance from what is known from other areas. As a first priority, a comprehensive review document will be prepared, which will summarize available scientific literature and nonpublished sources on the occurrence and distribution of marine mammals within the SPREP region. Next, a program will be developed to collect information from knowledgeable local sources on the occurrence of marine mammals within each of the SPREP member countries. At the same time, education programs will be started in each country to teach local people about marine mammals and conservation issues. An identification guide, poster, and reporting form will be developed for widespread distribution throughout the region in order to improve the knowledge of marine mammal distribution.

- **Marine mammal threats.** Simultaneous with the collection of basic data on marine mammal populations, an assessment will be made of the threats to marine mammals of the region. At present known threats include: incidental and directed fisheries, habitat loss, environmental cataclysms (e.g., nuclear explosions, volcanic eruptions), and the effects of pollution.

- **Establishment of a database.** A database will be established by SPREP to hold information on sightings, strandings, and takes of marine mammals, both directed (harvest) and incidental (in fishing operations).

- **Research and conservation plan.** From the information gathered from local, regional, and international sources, a series of comprehensive research and conservation projects will be implemented and support sought from a variety of sources.

- **Urgent programs for immediate action.** Even with the present dearth of information on marine mammals in the SPREP region, there are several programs that need to be started immediately including:

  (1) Assessment of dugong populations throughout the region and the threats to these populations. Since dugongs live near shore in estuarine and riverine ecosystems, they are particularly vulnerable to human

activity, habitat loss, and directed and incidental fishing. Interviews with local people and surveys of potential habitats must be conducted throughout the region. Once critical habitats and populations have been identified, conservation measures need to be taken.

(2) Development of a local program for handling strandings, in particular, that will include release of animals sufficiently healthy to warrant release and careful dissection of dead specimens and sharing with specialists of tissues, collected and preserved according to existing protocols.

(3) The SPREP region contains breeding areas for both northern and southern hemisphere humpback whales, perhaps the most endangered species of large whale regularly found in the area. It is important to develop and implement throughout the region a coordinated program of research on humpback whales using well-established techniques now in use world wide. Research should initially identify humpback whale breeding and calving areas in the SPREP region. Next, by using photographic and genetic individual identification methods, the relationships of stocks in the SPREP region must be identified, both between breeding areas of the region and to high latitude feeding grounds in both hemispheres. Programs must also be started to monitor the recovery of humpback stocks in the South Pacific that will include research and appropriate management steps to protect critical habitats. It is also advised that, where appropriate, SPREP monitor the development of whale watching programs and the associated impacts on the animals.

CONCLUSION

While some populations of marine mammals are restricted in distribution, others are highly migratory and move freely through the region, both within exclusive economic zones (EEZs) and on the high seas. Therefore, conservation of marine mammals of the region cannot be achieved solely by measures at the national level and requires a coordinated regional effort. Thus the SPREP framework provides an ideal opportunity and mechanism to carry this out. The biggest obstacle in completing this conservation plan is funding. The SPREP marine mammal conservation plan is presently at the stage of seeking funds from both national and international organizations for full implementation.

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